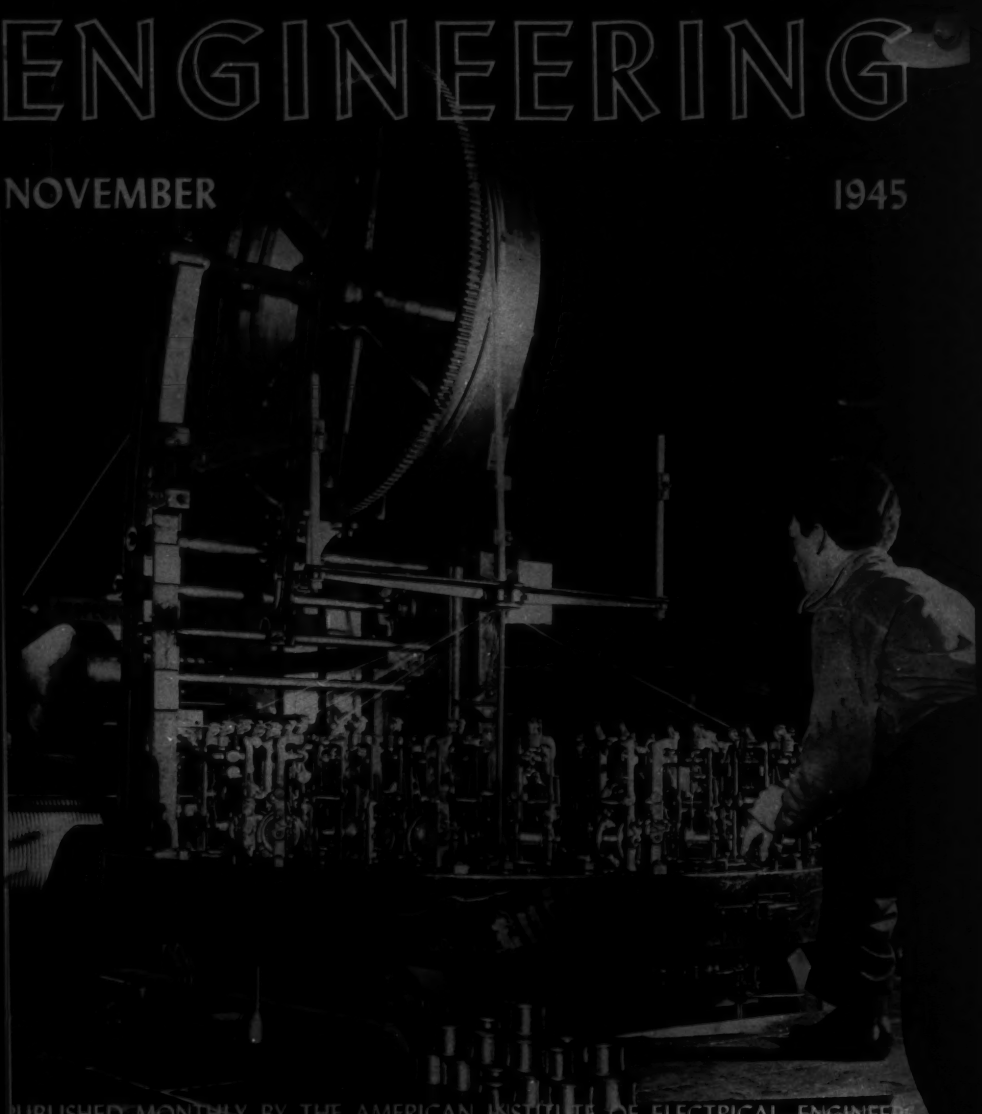
ELECTRICAL ENGINEERING

NOVEMBER 1945



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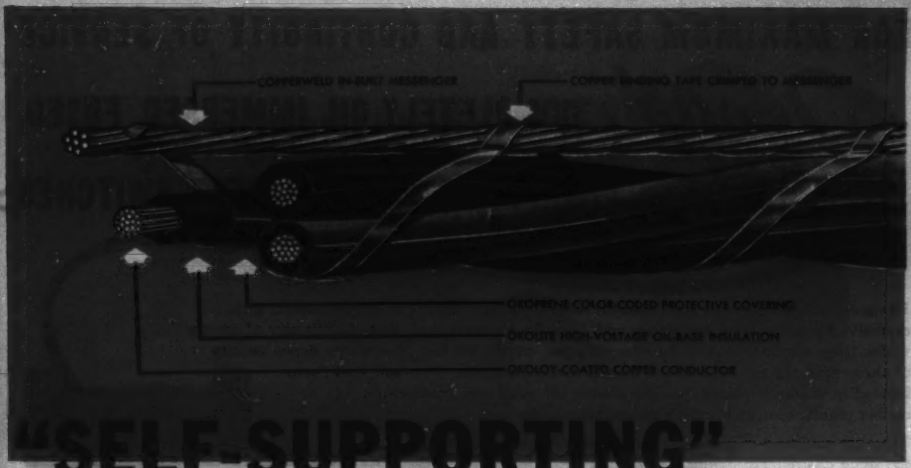
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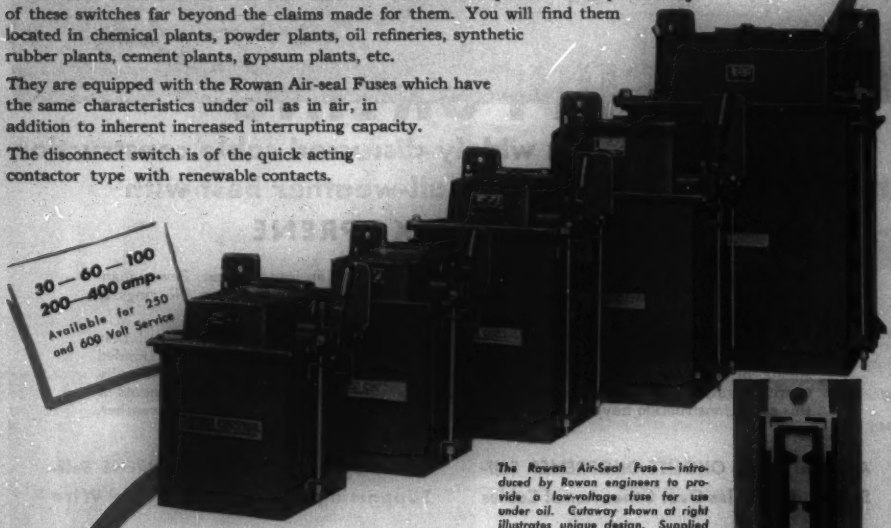

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The Cover: Braiding machine in a radio-frequency-cable manufacturing plant; a report of a conference on these cables will be included in the 1945 *Transactions* volume and in the December 1945 "Supplement to Electrical Engineering—Transactions Section" (*see p. 409*).

Federal Telephone and Radio Corporation photo

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Statements and opinions given in articles and papers appearing in *Electrical Engineering* are the expressions of contributors, for which the Institute assumes no responsibility. ¶ Correspondence is invited on all controversial matters.

Published Monthly by the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Founded 1884

VOLUME 64
NUMBER 11

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ELECTRICAL ENGINEERING
VOLUME 64, NUMBER 11 NOVEMBER 1945

Engineers and Scientists in Government Service

RALPH D. BENNETT
FELLOW AIEE

DURING THE WAR the armed services employed, either directly or indirectly, most of the best technical talent of the United States. The larger fraction was indirectly employed through industrial concerns having contracts with the armed services, or through the National Defense Research Council. However, a considerable number was in direct employment with agencies such as the Signal Corps Laboratory at Fort Monmouth, N. J., the Army Air Forces Laboratories at Wright Field, Ohio, and, in the vicinity of Washington, D. C., the Naval Research Laboratory, the David Taylor Model Basin, and the Naval Ordnance Laboratory. The writer's association with the last-named organization enabled him to observe the expansion of that laboratory to war strength and its operation under war conditions. It is on these observations that this article is based.

The problems of civil-service operation, with particular emphasis on the hiring and rating of technical talent, are considered in this article which is based on the author's experience in the Naval Ordnance Laboratory, Washington, D. C.

CONDITIONS IN SERVICE LABORATORIES

The onset of the emergency found the Naval Ordnance Laboratory understaffed for its job. It had operated on very small budgets for many years with the result that its technical talent had been stifled and restricted, and its contacts with the outside world were extremely limited. The situations of the other service laboratories were different only in degree.

In the light of developments of the last five years, the wisdom of allowing our service laboratories to languish in such a manner becomes extremely doubtful. For the lack of modern weapons, or countermeasures to modern weapons, many lives were lost. We spent billions for development of weapons under the pressure of war, where millions spent in a careful, logical, peacetime program would have sufficed. We scurried frantically on many occasions to work out countermeasures to new enemy weapons against which we were totally unprepared. And we were reduced time and again to copying weapons introduced by the enemy because they were better than those which we, with our late start, were able to develop on our own.

After the first World War we sought peace by discarding our weapons and hoping that the anarchic nations would follow our example. This procedure was unsuccessful and it is hoped that we do not try it again, even under the pressure of expedient economy. During this peace we shall have to maintain more effective armed forces than ever we have in the past.

The effectiveness of an armed force depends on its size, the mental and physical qualities of its members, and the quality of the weapons with which it is provided. In numerical size, and particularly in quantity of equipment, we were able to compete with all comers. In fact our great supply of equipment may have proved a definite hazard as there is every reason to believe that by the time it is needed again it will be obsolete and, if retained, may give us a false sense of security. In mental qualities, at the present state of practical genetics, we had to work with what was available, but we must not continue to let our educational program deteriorate. Our widespread technical education allowed our Armed Forces to use weapons more complex in nature than those of many of our allies and enemies. The inability of a large fraction of our young people to pass the physical requirements of the services is a cause for concern. The proposed universal military service will help this situation somewhat, and this may be its principal contribution to national security.

The primary requisite in the effectiveness of an armed force in modern war is the quality of its weapons. The maintenance of this quality for our Armed Forces was and will be the responsibility of our research and development organizations, and particularly those of the armed services. Therefore an examination into the difficulties encountered in the operation of these organizations is in order, with a view to strengthening them and improving their effectiveness, particularly in peacetime.

The effectiveness of a research and development organization depends upon men and facilities. With the assumption that facilities will be provided, since this is relatively easy, the promotion of effectiveness then becomes a matter of getting high-grade men and keeping them productive. The Government is under a handicap in both respects because it does not make a sufficiently aggressive effort to get the men, and because artificial restrictions seriously hamper the activities of those it does obtain. The restrictive procedures are particularly inappropriate when applied to research and development men because the value of these men lies in their originality and willingness to deviate from the established channels of thought and action.

GOVERNMENT HIRING METHODS

The expansion in technical personnel at the Naval Ordnance Laboratory was accomplished by means of contract hiring, a method commonly incorporated into Naval and other appropriation bills, whereby the bureaus may contract for the services of scientists and technicists at a fixed daily rate. The method was rather simple to operate, flexible in the adjustment of rates, and generally satisfactory for temporary employment. However, when the number of persons so employed be-

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Essential substance of an address delivered before a meeting of the AIEE Washington Section, October 10, 1944.

Ralph D. Bennett is a captain in the United States Naval Reserve, Naval Ordnance Laboratory, United States Navy Yard, Washington, D. C. He is on leave from the department of electrical engineering, Massachusetts Institute of Technology, Cambridge, Mass.

came large, pressure was exerted toward the transfer of these persons to civil-service status. The terms of transfer gave Naval Ordnance Laboratory employees an increase in salary averaging several hundred dollars per year, in addition to the privileges of annual leave, sick leave, and retirement benefits. Yet the employees of the laboratory for the most part were reluctant to transfer, and a considerable number of the ablest men left the employ of the laboratory when the issue was forced. The most common reason given for reluctance to transfer was that the employee wished to keep his record clear of the stigma believed to be associated with a term of civil-service employment. While other motives were involved in some of the resignations, the feeling was very real and very strong. Unless this feeling can be alleviated in the minds of those from whom our governmental employees must be drawn, we shall continue to have difficulty in getting enough superior talent. The reasons for this attitude are multifarious and complex.

A superficial reason that active, energetic technical men often do not aspire to governmental employment is that they too rarely see persons of great technical accomplishment in such employ. There are two possible reasons for this; first, the Government may not hire its share of talented individuals, and second, for those of talent whom it does employ it too often fails to provide proper encouragement and an atmosphere in which latent talent can develop. Even when latent talent develops, the employee himself usually must furnish the stimulus to publicize his accomplishments.

Considering first the matter of hiring of technical men, governmental techniques are inadequate as judged by modern standards. For the great majority of positions, the procedure briefly consists, in normal times, of posting notices of examinations in public places, examining those who appear and present appropriate paper qualifications, scoring the qualifications and examination, and placing the names in order of standing on a "register." When a vacancy occurs, the agency in which it arises chooses from the top three names on the register. The agency in general will have only a paper record on which to base its choice. It will know little of the personality of the candidate and therefore will be in a poor position to estimate how well the candidate may fit the group in which it is proposed to place him. To remedy this the agency should have the authority and the funds with which to pay the expenses of prospective employees called in for interviews.

INDUSTRIAL HIRING METHODS

Contrast this system with industrial recruiting as practiced in normal times. The candidate has to make no application, fill out no forms, take no examinations, and await no rotation of registers. Representatives of the interested company visit his school (if it has a reputation for sound training) well before graduation time, examine his personal history and scholastic record, interview the candidate and his professors at some length, and if mutual interest arises may provide the candidate with a trip to the company's establishment. The candidate, if accepted, can go to work in a predetermined job at a predetermined time. He generally will be provided with much more information regarding the organization with which he is casting his lot than he would be likely to get if he were to go into governmental service.

Competition on this basis too often has an outcome unfavorable to the Government. In too many cases candidates for jobs apply to the Government only when, because of poor performance or personality defects, they have failed to find placement in industry. To remove this basic handicap, those having the responsibility for government employment of technical personnel must, among other things, set up an aggressive recruiting procedure in order to get a fair share of good talent. Furthermore, while the supervision of selection of technical employees may be carried out by a general agency such as the Civil Service Commission, the actual selection of individuals cannot be delegated successfully to such a general agency without setting up a severe handicap to building a strong organization of high quality. Each organization must be allowed more freedom in selecting its own personnel. Frequently the fourth or fifth man on a civil-service register is obviously better qualified for the position than any one of the first three.

Successful recruiting of personnel is associated closely with the measurement of ability and accomplishment. The measurement problem is formidable and no perfect solution can be expected. The value of a technical man may be assessed on two major factors, namely, straight technical training and experience, and personality. The former is relatively easy to evaluate, and is given fair consideration in present governmental methods of employment. Personality evaluation, on the other hand, is much more difficult, largely because the evaluation is subjective. The industrial method is to provide a trusted and experienced evaluator who obtains his data by means of interviews and inquiries. The Government has no equivalent counterpart. While personality is of relatively little importance in the lower grades, it is the primary factor on which leadership is based. Without a conscious effort to take personality into account in the employment of its personnel, it is hard to see how the Government can avoid continuing to find itself deficient in material from which leaders can be made.

A factor which is causing much concern at present in many Federal agencies is the preferential treatment granted veterans. A concrete example of the working of this law, together with an inadequacy in present measuring methods, has come to the writer's attention. A professional scientific position of intermediate grade was open. Two candidates were available. One was a recent graduate in his early 30's with an advanced degree, who had finished with distinction in a school of established reputation, and whose interests and outlook well fitted him to fill the position and to become a strong member of the organization. The other, a veteran in his late 50's, finally had failed after a long career of teaching in an inferior institution. According to the law, with his veteran's preference, the latter had a prior claim on the position. Obviously such a candidate would become a clinging liability to the organization. Fortunately it was possible to leave the position unfilled pending a more propitious outlook, but the organization lost the services of a young man who might have contributed much. The present law gives veterans such a great artificial advantage that it seems unlikely that any persons other than veterans will be employable by most agencies for many years. While in purpose the law is commendable, no doubt a method could be found for accomplishing the desired result which would be less expensive than making certain, as the law certainly will in many cases, that persons of inferior basic qualifications are selected to operate the Government, our biggest and most expensive industry. The law should not make mandatory the placing of veterans in the top three positions on a register, over the heads of more able and more desirable candidates.

MEASUREMENT OF EFFICIENCY

The measurement of "efficiency" is another problem which is solved very imperfectly. While the present system is the outgrowth of many arduous and sincere efforts, when applied to technical men it still seems to have several salient defects. First, a rating blank is used which is designed to cover a wide variety of jobs, and hence is particularly suitable for none. Second, the grade is reported in detail to the employee, which puts the supervisor in a position of having to defend his grading. This has obvious merits, but since a low grade is likely to cause unpleasantness no matter how well merited, and there is no penalty for giving an unjustified high one, nearly all grades are high. The average for those agencies for which the information was available lies somewhere between the highest and the second highest of four satisfactory grades, with over 80 per cent in these two categories. With this narrow spread of grades the ratings are of little use in judging relative or actual value of the individuals of a group. A system of pay increases such as now exists based on these ratings becomes of doubtful incentive value. A possible remedy is to provide a form which will be better adapted to evaluating technical

men, so designed that a differentiation will be made over the scale of effectiveness, evolve and take into consideration an index for each supervisor based on the severity with which he grades, and use the results in a realistic manner for the improvement of the service.

Except for a few of the most highly responsible positions, a Federal agency under the current regulations becomes a collection of jobs, which can be and are described on paper, and "allocated" by a reviewing agency into categories according to responsibility and difficulty. These jobs are viewed as entities, detached and separate from the persons who do or may occupy them. Each pays a predetermined salary according to its category. Similarly each person is viewed as another kind of entity to which a grade or magnitude can be attached, based on training and experience. Staffing the agency then becomes a matter of selecting an appropriately tagged individual for each labeled job. The individual's tag must indicate that he is qualified to hold a job of as high or higher grade than the one into which he is to be inserted. Promotion then becomes a matter of moving individuals from job to job as the jobs are vacated by promotion, resignation, or other contingency.

While this conception of an agency tends, theoretically at least, to insure that money will not be spent to pay persons for whom no real jobs exist, it runs into difficulties in a research and development organization. In the first place, in a live organization of this type the jobs change with kaleidoscopic frequency and variety. Therefore, to keep the job descriptions current and accurate is a Herculean task, and the work involved even in approximating this goal constitutes a severe drain on the strength and patience of men who are trying to do scientific and technical work. In the second place, under this system, no means is provided for hiring the type of creative genius which makes its own job, and without whose presence the job does not exist. Actually, under the pressure of war, such persons were hired, but in normal times for the civil service to hire a man, as contrasted to filling a job, is not an acceptable procedure. Since a research and development organization, by its nature, counts progress by the unpredictable results flowing from the work of creative people, the lack of a straightforward method of employing such men is a serious handicap. In the third place, men who make substantial progress usually are not content to wait for circumstances beyond the control of their employers to remove the person ahead of them.

The static nature of governmental agencies is enhanced by the fact that persons of long standing in the service are too rarely qualified for, or interested in, other employment, and even more rarely leave the service. Even though the law provides for it, they are rarely moved out but, unfortunately, sometimes are moved up, even though of doubtful competence. This may result in further enfeeblement of leadership which is already none too strong. A factor which tends to prevent the infusion of new blood and tends to advance incumbent incompetence is the substantially higher qualifications necessary for an outsider to move into a job over those required of an insider to move up. Still another factor obstructing advancement is the difficulty in getting technical jobs appropriately classified. The law provides for recognition of technical responsibility as independent of administrative responsibility. However, the administration of the law as far as classification is concerned is often in the hands of persons of clerical training and background. To such persons the pyramidal type of clerical organization is familiar and understandable. But to them the evaluation of technical responsibility in an unfamiliar and little understood field is difficult and often requires much discussion and delay.

In order that we may have more effective governmental research and development organizations, the concept of an agency as a group of jobs to be filled must be liberalized, provision must be made for the employment of the person who creates his job, and the unusually gifted must be encouraged and rewarded more generously and promptly than has been possible in the past.

THE SALARY INCENTIVE

Before the war the pay scale for the purely technical person was, by and large, adequate, save for the senior positions. The pay in the initial grade was some 30 per cent higher than that for corresponding positions in industry, and annual leave, sick leave, and retirement benefits were relatively liberal. The recent adjustment is not likely to meet postwar competition in the higher pay levels. For these positions, which were relatively very much underpaid as compared with work of similar responsibility in industry, the new law provides relatively small pay increases. The superior rates in the early grades probably facilitated and will continue to facilitate the hiring of young men, but they tend to attract the shortsighted. The difficulty in achieving recognition of purely technical responsibility already mentioned in part limits access to the higher rates of pay to fewer persons than is desirable in a research organization. The pay scale fails by all comparative standards to provide adequate rates for high administrative positions. When the Government asks a technical man to leave his technical specialty and undertake the responsibility of the administration of a technical organization, it does not, as in industry, reward him by a substantial increase in salary. This is an important factor in the existing situation where persons of superior leadership who have proved themselves cannot be induced to enter Government service unless they are privately endowed or willing to take a substantial loss in income. Similarly, there is relatively little inducement for a Government employee who demonstrates leadership to stay with the service, since in the service he never can be rewarded in a degree comparable to that which he can receive in industry. Many of the ills of the present system are directly attributable to this failure to provide for superior leadership and they can be expected to persist until this need is recognized and satisfied.

PROFESSIONAL DEVELOPMENT

Those responsible for the operation of governmental technical agencies often take too little interest in the continued development of their professional employees. The appropriations made for the purpose of sending naval professional employees to technical society meetings has been comparable in the past to that provided by a medium-sized university, employing perhaps one-tenth the number of professional personnel. This contributed to the condition at the start of the war in which a great many of the naval technical employees not only were ignorant of recent technical and scientific developments, but they were unacquainted with the authorities and organizations which could instruct them or supply their needs.

Publication of the results of researches provides a most valuable means for furthering professional contacts and stimulating creative work. Workers in the laboratories of the Armed Forces suffered a serious disadvantage in this respect because of security requirements. However, much of their work can be published and it is essential that the most liberal policy possible be employed in this matter. The contacts lost by lack of publication in a measure can be replaced by other procedures such as the interchange of personnel among research activities within the services, the detailing of personnel for substantial periods to university or industrial laboratories, or by arranging exchange visits between specialists in service and industrial laboratories. The Naval Ordnance Laboratory has found industry very receptive to such proposals. The Naval Laboratories can do much to stimulate interest by sending their technical men to sea for short periods. Many such methods are available to leadership alert enough to recognize and insist upon the importance of professional development.

Another problem in the operation of a Government research and development organization which is not a personnel matter, but adds to the difficulty of interesting competent men, is the complex purchasing system under which they are required to operate. The desirability of a system designed to hold cost to a minimum is obvious. However, when applied in

detail it may defeat its purpose as the process of acquiring an item at minimum cost may introduce frustrating delays which are expensive out of all proportion to the immediate amount involved. This is largely the result of the establishment of regulations to control purchase of large quantities of routine types of material without recognizing the highly specialized needs of the technical worker for material which costs relatively little. A wider opportunity for the application of judgment should be allowed in the purchase of equipment and supplies in experimental quantities.

The preceding recital of current difficulties with governmental employment of technical men combines to present a gloomy picture. However, out of fairness to those who have struggled with the problems of government employment through the years, and to those scientists of agencies such as the National Bureau of Standards, the Department of Agriculture, and similar establishments, who have made substantial contributions in the face of these difficulties, the progress made in the past should not be forgotten. The Government technical administrators have highly ethical standards and, if given a free hand, the technical agencies of the Government would be operated more effectively than at present. However, experience in the United States indicates that such administrators would not long have a free hand. Irresistible political pressure soon would be brought to bear to the great detriment of any agency susceptible to it. The civil-service system was established primarily as a bulwark against such devastating pressures and has served well in that capacity. While eliminating former evils, the system has brought new ones which, while less vicious than those which existed previously, are nevertheless in urgent need of correction. The war focused widespread attention on these evils. The present is a propitious time for improvement and, while the process undoubtedly progressed slowly from the point of view of national defense, it would need acceleration if we are to reach and maintain a leading place in readiness to defend ourselves.

SUGGESTED IMPROVEMENTS

The principal steps needed to effect substantial improvement in the governmental technical service may be summarized as follows:

1. Achieve substantial and durable public recognition of the value of a comprehensive governmental research and development program.

2. Acquire in technical agencies a superior leadership which will utilize the provisions of present laws and regulations to their fullest and most beneficial extent and which will point out articulately changes which are needed. Such leadership must be compensated in cash and prestige.

3. Prosecute an aggressive recruiting procedure which will present the needs of the governmental technical agencies in a modern, imaginative manner and will compete energetically for technical talent at its sources.

4. Improve the measurement of technical talent so that governmental evaluation of quality in a technical man will agree with the judgment of his profession, and hire and promote on the basis of such measurement.

5. Recognize that genius creates its own job, not fills one prescribed by men of lesser imagination; and make provision for a fair share of genius in the Government.

6. Provide for and insist on continuous professional development in its broad sense on the part of technical employees, as an essential for continuation or advancement.

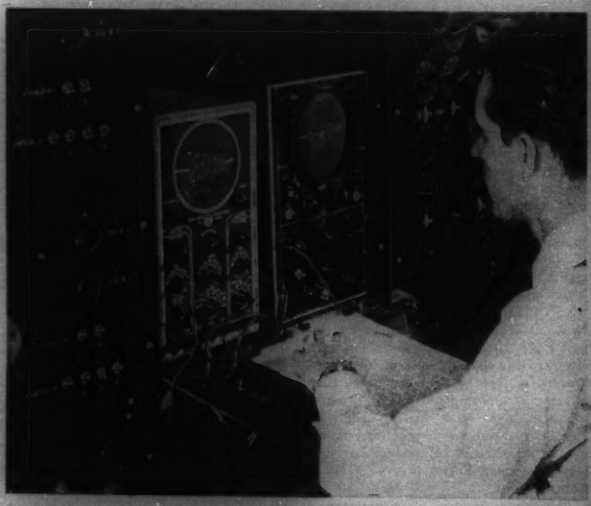
7. Effect the most liberal interpretation possible of the requirements of security as applied to publication by members of the laboratories of the armed forces.

8. Refuse firmly the promotion of mediocrity, and encourage the promotion of talent by provision for humane disposal of the decadent.

9. Provide flexibility and speed in the purchase of experimental materials consonant with an over-all conception of cost.

The persons responsible for the execution of the naval research and development programs are well aware of the difficulties that have been outlined and are ready to exert great effort in alleviating them. However, many other groups, both within and without the Navy, are involved, and some of the remedies are so basic as to require action by the Congress. These groups whose responsibilities are indirect and widely inclusive deal with the great mass of Federal employees and their rules and regulations are designed for the mass. To meet the needs of the special group of technological professionals, which totals at present less than three per cent of the whole, presents a serious problem in the face of the demands of the other 97 per cent. Nevertheless, the increasing part played by technology in life in general, and in Government in particular, enhances the importance of this minority, and therefore its needs merit serious consideration. Failure to meet these needs in a way which will strengthen substantially the military research and development organizations of the country may leave weak a vital link in our national defense.

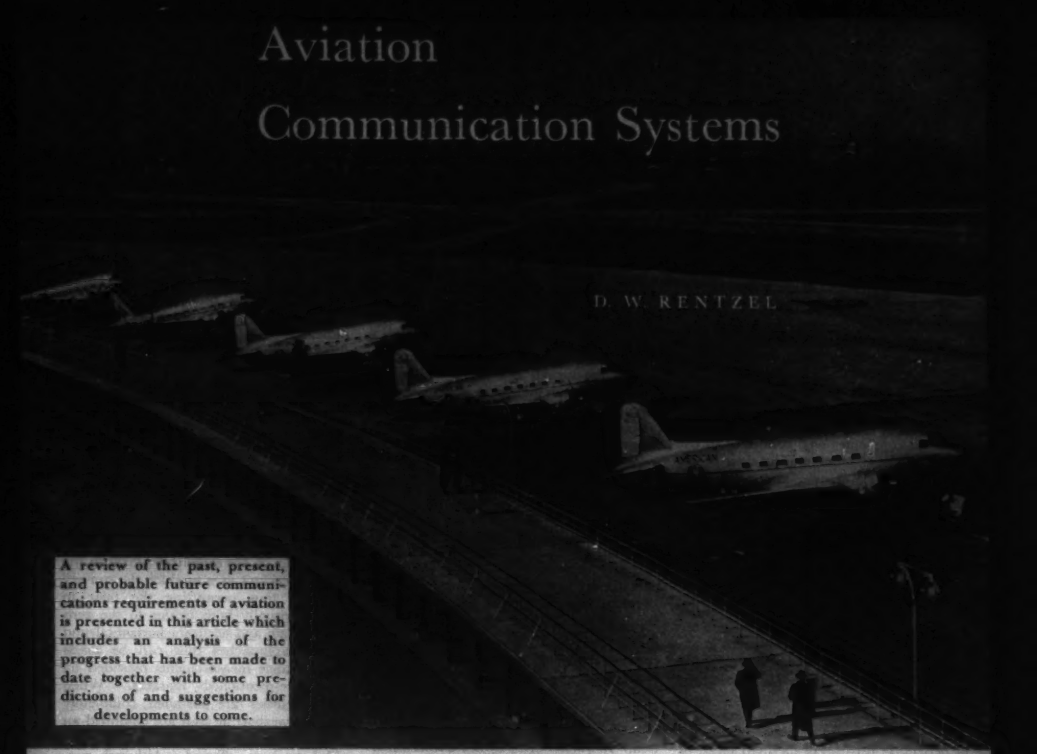
Robot Solves Equations



An electric robot "quiz master" which computes problems by means of electric circuits and transmits the answers through the lines appearing on the fluorescent screens showing the reactions of electricity in combinations of coils and resistors that simulate the mechanical factors in a problem. This apparatus, known as a mechanical transient analyzer, was developed by the Westinghouse Electric Corporation to aid its engineers by solving mathematical equations in a fraction of the time required by ordinary methods

Aviation Communication Systems

D. W. RENTZEL



A review of the past, present, and probable future communications requirements of aviation is presented in this article which includes an analysis of the progress that has been made to date together with some predictions of and suggestions for developments to come.

American Air Lines photo

TO DISCUSS at any length the many and complex needs of aviation for communications and the varied methods by which these needs may be met would require a great deal more space than is available. Aviation is the largest single industrial user of communications in the United States today. However, it is believed that a reasonably clear picture of the problems and needs may be established briefly and some suggestions may be offered in this article. Aviation is looking anxiously to the radio and electronic industry for the ultimate answer to problems yet unsolved. Until the members of the various communications groups and the manufacturers make available additional equipment in a form which can be used commercially, the needs of aviation for communications and air navigation cannot be fully met.

STATUS OF AVIATION

The history of aviation communications, and this term is used broadly to include the transmission by radio and electronic methods of all intelligence required to enable safe flight, naturally falls into two periods of development. The first period began shortly before World War I and extended to the years 1929–30. The second began in 1930 and extends to the present. The future era has begun and the utilization of developments since 1940 will open new and promising vistas to us.

The first records of attempts to use radio transmission experimentally from airplanes in flight to stations on the ground date back to 1910. The United States Army and Navy each tried out such apparatus as was available and were able to transmit intelligence by means of radio-telegraph signals for distances of from eight to ten miles. The idea at that time was to utilize aircraft for artillery spotting. As late as 1915 there was unanimity of opinion that an airplane never would be able to communicate beyond spotting ranges because of the limited weights which it could carry. This, of course, limited the size of radio equipment. But industry met the challenge and in 1916, in conjunction with the Navy, a scouting airplane radio transmitter was developed. Radio became of such vital importance during the first World War that the first military radio laboratories were established under the direction of men such as Rear Admiral S. C. Hooper and Colonel C. C. Culver. The necessary and vital research programs to develop aviation communications for military purposes, which were to benefit commercial aviation so greatly, were begun.

It will be noted that the Navy's problem in developing radio for its aviation needs was that of long-range communications for scouting purposes and direction-finding bearings. The Army's problem was short-range radiotelephone for artillery co-ordination. Both were accomplished successfully in close co-operation with industry in time to be available for World War I.

In 1919 the first publicized use of long-distance radio direction finding and communications for aviation occurred when the famous *NC* airplanes attempted their transatlantic flights. These airplanes were among the first to be equipped fully with radio, having aboard transmitter, receivers, trailing antenna, emergency batteries, wind-driven generators, and direction finders. The direction-finding equipment was to play a particularly important part in these flights as witnessed by the report of Lieutenant (now Rear

Essential substance of an address before a joint meeting of the communications groups of the New York Sections of the AIEE and the Institute of Radio Engineers, April 26, 1945.

D. W. Rentzel is president, Aeronautical Radio, Inc., Mineola, N. Y.

Admiral) A. C. Read that but for direction-finder bearings he would have become lost between the Azores and Portugal. Thus, for the first time, the part radio was to play in the navigation of aircraft as well as a means of communicating with aircraft was graphically illustrated.

The first radio beacon, known as the radio phare, was developed in 1917 and came into extensive use for international aviation in the period which began in 1928. In this same period the need for navigation of aircraft along a fixed airway brought forth the development and test of the first radio range in 1929.

Radiotelegraphy for communication to aircraft was used for some years but the development of radiotelephone for this purpose was begun in 1929 and by 1930 airlines had adopted radiotelephone entirely, with the exception of the international companies who continued to use both types of emission to meet their needs. At the present time more and more radiotelephone is being used for air–ground communications in all types of aviation.

At this point it is worthwhile to explain briefly the broad requirements of aviation for radio communications and navigation. These can be listed best in order of appearance as operating functions on airplanes.

First; the need for two-way communications with ground stations. For obvious reasons the airplane must rely on radio to establish and maintain communications with the ground. Such communication must be instantaneous and reliable to the point of perfection because of the high speed of the airplane and its limiting factors such as inability to stop and wait for further information, and fuel limitations requiring a landing within certain time limits. It is extremely important, therefore, that weather information and meteorological data, airport conditions, and other pertinent facts be transmitted promptly to the airplane throughout its flight between points. This can be described as long-range communications.

After arriving at the point of intended landing or, in the case of airplanes operating in the vicinity of airports only, such as training flights, two-way radio communication is vital to segregate the airplanes in the vicinity properly and to give each airplane up-to-the-minute information on the sequence of landing, wind direction and velocity, and the condition of the airport and its runways. It can be described as short-range communications.

Secondly; a basic method of navigation between points. As mentioned briefly before, the airplane, as it is not bound by highways and other surface deviations and can fly directly to its point of intended landing, must create its own track in the air space. Obviously wind direction and velocity play an important part in such navigation, and the heading of the plane to achieve its straight flight path must be corrected. In clear weather this is done by visual reference to ground points in daylight; or reference to rotating light beacons at night; but, when low hanging clouds or fog reduce or eliminate visibility, radio must step in and create the safe track required. This is done at present by the radio range and radio beacon.

Briefly, the radio range operating in the 200- to 400-kilocycle band creates a path known as a beam or "on course" in four directions simultaneously by alternately keying four towers placed approximately in the shape of a square. By using the interlocking code signals *A* and *N* and alternate tower radiation the point at which the signals are heard with equal intensity blend into a steady monotone forming on the course or beam. Obviously the position of these on-course indications or beams in air space can be regulated, with certain limitations, by the placement of the towers and relative field strength radiated from each of the towers. By proper location of a network of these radio-range stations and co-ordinating their on-course indications to coincide, within adequate signal distances, airways in space are created permitting safe flight between any two points served by such facilities without any visual reference to ground points.

Such a system can serve any number of airplanes simultaneously. It is limited only by the spacing of airplanes to avoid collision. This spacing can be accomplished by vertical or horizontal separation. In other words, by altitude or time. The limitations of the present radio-range system will be discussed later.

Thirdly; a means of proceeding from the radio-range station to the airport under conditions of poor visibility. Although radio-range points are located near the airports they serve, a method of proceeding from the range station to the airport under conditions of poor visibility must be provided. This was accomplished until recently by arranging range-station locations so that one on-course indication passed over the airport providing a safe letdown path between the range station and the airport. By applying planned and tested procedures this method is satisfactory, with the limitation that sufficient cloud height and visibility are required over the airport for the airplane to maneuver safely underneath cloud cover after establishing contact with the ground in order to complete the landing. After considerable experimentation a supplemental program of installation of instrument-approach radio systems was inaugurated last year to augment military facilities already operating throughout the world. This approach system provides a runway radio beam or on course with marker stations located at proper points along the beam to indicate distance from the desired runway. The runway beam is formed by two modulation frequencies being transmitted simultaneously on separate and adjacent antennas. This results in overlapping bean-shaped lobes which create an electrical-equisignal on course on an indicator in the cockpit of the airplane. The on course or electrical-equisignal zone of this beam is centered on the desired runway, thus setting up a runway path. The marker transmitters located along the beam or on course, at known distances from the end of the runway, transmit an elliptical vertical pattern. A flashing-light indication and an aural indication in the headphones when the airplane passes over the marker station indicates exact position to the pilot. A third transmitter known as the "glide-path" transmitter is to be added to these ground installations soon. This transmitter will provide a beam in the horizontal plane indicating safe-glide angle through surrounding obstructions. This glide angle is established by the same methods used for the establishment of the localizer except that, in effect, the transmitting antenna are turned 90 degrees. Indication of the airplane's position in the horizontal plane is shown by the position of a needle on the same instrument in the airplane cockpit as is used for the runway localizer, thus permitting the pilot to bracket visually both beams to the zero point. Safe and accurate horizontal and vertical approaches thus can be made with distance measurements provided by the afore-mentioned markers. When these facilities are installed completely and all transport aircraft are equipped an increase in operating efficiency and safety will have been effected. Although personally owned aircraft may use these facilities, it is expected that because of the weight and cost of the airborne equipment such use will be limited for some time.

SUPPLEMENTAL NAVIGATIONAL DEVICES

Again, due to speed and other limitations, an airplane cannot rely solely on one means of navigation where daily flight regardless of weather conditions is contemplated. Therefore, scheduled or airline aircraft carry an additional device known as the automatic direction finder. This unit operates on the radio-range band, the standard broadcast band, and a supplemental international beacon band above the broadcast band, and gives a homing indication to the pilot when tuned to the desired station. It has proved valuable in checking navigational paths and in obtaining wind-drift indication. In operation over large bodies of water, in the international service, where radio ranges are not provided, it has become a primary means of navigation, as a supplement to celestial navigation fixes. Lately new long-range navigational devices have been added. The automatic direction finder operates by automatic homing on the balanced-loop principle of a shielded loop measured electrically against a sense antenna out of phase with the loop. A

received signal will cause the loop-motor mechanism to rotate until a null is achieved. By direct reading methods this loop position is indicated by an arrow on an azimuth scale in the cockpit thus giving homing indications continuously on the desired station and tracking the station when the airplane is maneuvered. Tracking information is invaluable to the pilot for many purposes.

Ground direction finders also are used extensively in the international service operating on the communications channels in the high-frequency band. In the European areas low-frequency transmissions from the airplane also are used. The latest versions of these direction-finder stations operating in the high-frequency band give electrical azimuth indications, from a rotating loop or loops of the incoming signal and serve well as an auxiliary indication of an airplane's location. Obviously triangulation fixes are only a matter of co-ordinated ground direction-finder stations. It is expected that such stations will continue to be useful, operating in the high-frequency bands for the international overseas aviation service, particularly in air–sea rescue work, and as a supplement to other facilities for emergencies.

FREQUENCIES

The frequency problem is of particular importance to aviation because of the time conquering attributes of the airplane and its disregard of geographical barriers. Aviation never can expand properly unless frequencies, procedures, and methods of navigation are standardized broadly internationally. Otherwise, unnecessary stops, duplications, and complications of airborne equipment and complexity of procedures will retard the growth of aviation between countries and throughout the world.

Frequencies for communications. Present frequency bands used for aviation communications are largely in the high-frequency bands. Those used domestically are concentrated in the 3-megacycle and 5-megacycle bands and internationally 6-megacycle, 8-megacycle, and 11-megacycle bands are added to provide optimum frequencies for long-distance operation over large bodies of water. These frequencies have proved very satisfactory, making possible continuous communications over extreme distances with the limited power and antenna characteristics of the airplane. A trend toward the very high frequencies for certain types of communications, particularly short-range control, now has been initiated to supplement the high-frequency channels, so valuable for all types of international services, and therefore extremely limited. Very-high-frequency bands allocated to the aviation services by recent Federal Communications Commission proposals provide a band 122 megacycles to 132 megacycles for communications purposes and 75 shared channels in the 225-megacycle to 400-megacycle band. From these bands will come channels for privately owned or personal aircraft, commercial, scheduled and nonscheduled aircraft, and lighter-than-air ships. Operating on 118 megacycles to 122 megacycles will be control stations transmitting to all types of aircraft. The latter stations include the military when using commercial airports.

The high-frequency band, while permitting long-distance communications between aircraft and ground stations, has certain disadvantages which can be offset to some extent by the very high frequencies just as high-frequency bands offer very definite advantages and disdavantages over the low- and medium-frequency bands to aviation.

High-frequency channels, being affected by movements of the heaviside layer, require channel assignments in pairs, or a family of frequencies in the case of international long-distance aviation, to provide day and night coverage in skip conditions. Lower frequencies are used at night and high frequencies in day to cover the same distance. This complicates the airborne equipment and requires multichannel transmitters and receivers. At the present time, ten channel transmitter–receivers weighing 65 pounds with an output of 60 watts are standard. The long-distance-transmission features of the high-frequency bands also limit the number of times a frequency may be shared without interference which requires more channels to be assigned. However, these features are also advantageous in long-distance operation on low power and the high-frequency band is the only band having this advantage. High frequency bands also are affected less by static than are low and medium bands but very-high-frequency bands offer almost staticless communications. Very high-frequency, however, as is well known, being limited to line-of-sight communications offers complications to low flying aircraft. Repeater stations, or considerably more stations, are required to maintain the continuity of communications required and cannot be used extensively in the international aviation services or for long-distance domestic-aviation services because of the impossibility of providing the necessary stations over large areas of water, jungle, or undeveloped territory. Very high frequency also has some disadvantages in extremely mountainous terrain for the same reasons so it is necessary that both bands be used to cover the needs of all types of aviation for communications with future emphasis on very high frequency.

Very high frequency offers some weight saving as a result of lower power requirements. The shorter lengths of antenna required present a definite advantage to aircraft as it is possible to house some antennas inside the surface of the airplane or greatly reduce exterior lengths of antennas and so reduce aerodynamic drag. Provision of antennas of better radiation characteristics is also possible.

An additional band of frequencies in the vicinity of 1,500 megacycles has been proposed for assignment to aviation and it is to be hoped that these channels will be even more useful for limited-distance communications in the next five years.

One additional advantage of the very-high-frequency bands to aviation is the elimination, to a great extent, of the effect of the phenomena known as precipitation static, caused by passage of the airplane at high speeds through highly ionized cloud formations. The resulting high-voltage charge on the airplane's surface discharges across antennas with sufficient intensity, particularly in low temperatures, to cause receiver blocking and temporary loss of communication on lower frequencies.

Frequencies for navigation. At the present time, low and medium frequencies are being used for navigational purposes by aviation. As mentioned previously the radio ranges operate throughout the world in the 200-kilocycle to 400-kilocycle band. These are supplemented by radio phare beacon operations in the international service in the 1,600-kilocycle band, particularly in the central latitudes and for daylight operation. New long-range navigational devices for overseas operation operate in the 1,800-kilocycle to 2,000-kilocycle bands. These devices, using electronic methods for measuring distance from land stations, offer great promise for long-range highly accurate navigation for both maritime and aviation services and promise a great improvement over present methods of navigation over large bodies of water. Much experience has been gained in the last two years in the utilization of such facilities and consequent improvement in techniques.

At this time it might be well to point out that modern maritime and overseas aviation navigational practices and methods should begin to merge in the postwar era and close co-operation between the two services is indicated and extremely desirable. The supposed competition between the two types of service has no part in the safety services. Aviation is ready and willing to share navigational aids where possible.

Frequencies proposed for the instrument-approach facilities now being installed are 108 to 112 megacycles for the runway localizer and frequencies in 330-megacycle bands for glide-path transmission. Seventy-five-megacycle marker assignments are operated at present for both airway and approach markers but it is likely that these assignments will be changed to higher frequencies or possibly eliminated because of technical developments within a reasonable time now that the war is over. A considerable investment is represented, however, and for production and installation reasons alone the transition cannot be a short one.

A new band for radio ranges has been assigned from 112 to 118 megacycles. The present low-medium frequency assignments are far too crowded and are needed urgently for overseas and long-distance domestic service and must be supplemented by these very-high-frequency facilities for short-range service and low frequencies diverted to long-range needs. The prospect is, therefore, that very-high-frequency radio ranges will be in service soon and the domestic airways will be served primarily by these facilities. Instead of four "courses" established by aural methods the new ranges will be two-course visual indicating types and will provide electrical as well as aural on-course indication to the pilot. They will provide for more accurate identification of airplane position, the elimination of most types of static, and should be somewhat more reliable due to the absence of night effects.

These new very-high-frequency ranges will provide for conversion to omnidirectional types which will increase the number of on courses. Such a possibility offers many advantages, since, at the present time, all the air space between major cities is not being utilized by channeling air traffic, during conditions of poor visibility, along narrow airways. The omnidirectional range offers possibilities for creating more paths, therefore, and thinning out traffic congestion much as the opening of a new road or roads would do for automobile traffic, or the double tracking of a railway system would provide for additional railway traffic.

For experimental navigational purposes, to utilize the many new and promising devices over the horizon, Panel 11 of the Radio Technical Planning Board, representing aviation, requested, and the Federal Communications Commission concurred, in the assignment of bands throughout the very-high-frequency–ultrahigh-frequency spectrum providing for already existing facilities and new facilities now in experimental operation. One of the most important of these is the band 960 to 1,125 megacycles. Much hope is held for provision of a combination of several needs in this band which are to be described in the following paragraphs. Other bands offering especial promise at this writing are the 5,000-megacycle band and the band between 8,500 and 10,000 megacycles. However, with so many possibilities and developments, we cannot afford to overlook any possible solutions to our needs in any band.

MANY PROBLEMS UNSOLVED

The discussion to this point has been on what has been accomplished and what is now available in form satisfactory for use by commercial aviation. Many problems remain, however, which are crying loudly for solution at the earliest possible date. An attempt will not be made to present a too detailed discussion of these requirements, but this article would not be complete unless these needs were mentioned in general form. The items which are listed are not necessarily in their order of importance.

We are now looking to the "age of flight," the postwar period, in which radio and electronics must play a large part. The war period compressed many years of research on airplanes, engines, and radio and electronic equipment into a very few. Radio is guilty, at present, of trailing some of the other components of satisfactory and up-to-date air transportation and personal flying. Many of the factors preventing a completely safe and every day, on-schedule performance and the ultimate in personal airplane use are capable of solution only through radio and electronic methods. The solutions to many of these problems are in the offing, but they must be expedited and put into commercial form. The airplane user no longer is satisfied to get some place at some time. He expects and will demand dependable service and the ability to be assured of accurate arrival.

These are the major remaining elements needed to complete our aviation picture, capable of solution by radio-electronics methods.

COLLISION-WARNING INDICATOR

Pilots have always needed, and the need becomes more pressing with the increase in flying and flight speeds, some warning indication of obstructions, either mountains, buildings, or other aircraft. Unlike military requirements for similar equipment, full advantage should be taken of beacon transmitters on aircraft to identify other aircraft in the vicinity, and also to identify and locate obstructions. Such a device using electronic methods also could be used for continuous ranging from navigational beacons. Very general specifications for such an instrument should be:

1. Continuous scanning of an area of at least 15 degrees on either side of the center line of the nose of the airplane, preferably 90 degrees on either side of the nose, or a total sweep of 180 degrees. If possible that a substantial weight saving could be effected, the 90-degree sweep could be achieved mechanically by the pilot by some simple motor mechanism, the 15-degree sweep being continuous.

2. Should provide continuous distance indication, if possible on some type of counter device indicating distance in feet or yards.

3. Should indicate approximate elevation of obstructions with relation to aircraft position.

4. Should provide light or buzzer warning device when obstacle is within a preset danger area.

5. Weight should not exceed 50 pounds or should be less than 90 pounds if the instrument also serves as a radio altimeter and gives cathode-ray indication of azimuth location, distance, and approximate altitude of obstructions and radio beacons.

6. Should provide identification of all obstructions within 20 miles. Due to the high speed of new transport aircraft, this allows only four minutes or less for avoiding the obstruction.

7. Full advantage should be taken of ground stations to limit weight and power requirements in the airplane.

8. Power supply; should operate on 12- or 24-volt airplane system.

RADIO ALTIMETER

The radio altimeter was developed before World War II as a device to indicate heights above terrain vertically underneath. Some thought had been given to its possible use for instrument landing of airplanes to supplement the glide-path features of the instrument-approach system, but experience with its use indicated that needle flutter from obstructions in the path of the approach to the runway limits this use to water landings.

A new and important application for the radio altimeter has developed in overseas flights that makes its use advantageous for "pressure pattern flying" to take advantage of clockwise rotation of winds in high-pressure conditions, and counter-clockwise wind rotation in low-pressure areas as they move across the earth's surface.

Thus, by studying meteorological data before a long flight, a pilot may take advantage of these winds and not necessarily fly the shortest distance course, but fly the area having the best winds in order to afford the shortest time operation. The prime consideration in air travel is time, not distance.

The two most important instruments used in this method of "isobar" flying are the pressure altimeter and the radio altimeter. Variations in the reading of the two instruments give an accurate indication of pressure changes which, when analyzed, indicate regions of high and low pressure and indicate favorable courses.

The radio altimeter also is used to maintain clearance above terrain, proper elevation, and as a check on the accurate correction pressure-type altimeters.

It should have the following characteristics:

1. If possible, radio-altimeter functions should be combined with the collision-warning device.

2. Its range should be 40,000 feet, preferably on a low- and high-altitude scale.

3. Its accuracy should be at least within three per cent, with a stability of 30 feet over a period of 15 minutes.

4. Indication should be combined with the ranging measurement instrument, or on a counter type of indicator or cathode ray.

5. Some form of test button for service-test indications should be included.

AUTOMATIC POSITION REPORTING

One of the delaying factors in adequate air-traffic separation, in addition to the present channeling method mentioned in connection with radio-range systems, is

slowness in exchange of information concerning location of aircraft, between the air and ground, and between airplanes. Although anticollision indication will be a tremendous asset, separation and priorities of movement must be controlled by an independent controller on the ground in the same manner as a policeman serves at street intersections.

Air-traffic control, therefore, must become more automatic through the following or other methods to speed up aircraft movements, under conditions of poor visibility, to approximate movements in clear weather.

1. Automatic position reporting to identify, locate, and give altitude of all aircraft in the control area.

2. Ability to duplicate this information to all interested parties which may approximate as many as 50 duplications.

3. Azimuth identification and range indication to be automatic and, if possible, altitude of aircraft to be indicated on same indicator. If necessary, altitude indication can be separate.

4. Ultimate simplification in this device, keeping in mind all information to be obtained with lightest weight of aircraft equipment possible.

5. If possible, sufficient meteorological phenomena should be indicated to denote location, range, and intensity of thunderstorms, and other turbulent cloud concentrations.

6. Device should be capable of such housing that it can be operated in all elements.

7. Costs and unnecessary gadgets to be kept to a minimum.

WRITTEN COMMUNICATIONS TO AIRCRAFT

Because of the volume of information desired in aircraft, particularly in scheduled or airline aircraft, a means of written communication to airplanes is a necessary and desirable unit. Such a unit, whether facsimile or radio-type, used with area broadcasting procedures, would make available a volume of desirable and necessary data with no appreciable effort on the pilots' part.

General specifications might be described as follows:

1. Should be of the page type as tests have proved that tape printers are unsatisfactory because of the necessity of scanning for information and inability to tear out desired portions of tape without reloading or rewinding difficulties.

2. Printer or facsimile aircraft unit should not weigh in excess of 25 pounds, exclusive of the receiver.

3. Some consideration should be given to the possibility of station selection by providing extra pulse combinations for this purpose.

4. Aircraft unit does not require a keyboard or transmitter as a necessity, but should be developed in both forms, if possible.

5. Care should be exercised in feeding out the paper in a fashion that will avoid jamming when the unit is not attended.

6. Minimum band width for transmission is a very important consideration.

It will be understood that, for the purposes of this discussion, the lists of requirements must be kept to general terms. The foregoing list is confined to desirable operating characteristics and so is far from complete. Quite naturally, too, information of a classified nature cannot be discussed or explored as yet. Perhaps later articles will be able to develop this thinking further.

There are other important phases of aviation communications which will be presented briefly without taking the time to go into much desirable detail. These phases are described in the following.

Aircraft Electric Systems. Basically aircraft electric systems did not change radically, although they were vastly improved, from 1928 until the period just prior to the outbreak of the war when a shift from 12 volt to 24–30-volt d-c systems was inaugurated.

At the present time, most airlines and private or personal aircraft are still utilizing the 12-volt system, and most military aircraft have been utilizing the 24–30-volt system.

From a recently completed survey of aircraft electric systems, it was concluded that the basic electric system in all aircraft will be 24–30-volt direct current in the postwar period although, for many reasons, high alternating voltage will be available and quite possibly may be the primarily generated voltage. It was further determined that 400 cycles would be the frequency generated for high-voltage alternating current.

A further complementary study of this most basic aviation requirement is being undertaken by an AIEE subcommittee on aircraft electric systems. Aviation is deeply interested and will lend every assistance to the completion of this work.

Airborne Equipment. One of the other phases of aviation communications and navigation demanding immediate study is the size, weight, and scope of airborne radio and electronic equipment. Size and weight of airborne radio equipment is a matter of great economic concern since each pound carried in accessories is a pound removed from payload for passengers, cargo, or increased range.

Due to the method of growth of commercial aviation, a new unit has been added as each new function has been developed. The result is a large number of units almost totally unrelated with some units, such as marker receivers, being utilized as little as two minutes on an average flight, yet performing an indispensable service.

With the advent of the new frequencies in higher ranges being assigned in adjacent blocks it is now possible to combine two or more functions in one unit. We look forward, with the co-operation of industry, to development of one package of related and integrated units to perform all required functions. Such a system, it is hoped, can be operated from a common power supply and should not exceed 200 pounds in weight. For international overseas operation supplemental equipment peculiar to these long-range needs would be added.

A specific example is the combination of instrument-landing localizer and very-high-frequency radio range into one receiving unit. These functions being performed consecutively, this is a very logical combination, the receiver being designed to operate from 108 megacycles to 118 megacycles.

With the advent of new techniques, more packaging would seem possible, and more functions can be combined into a single unit on a time utilization basis.

The same principles of packaging apply to the personal airplane. The manufacturer who builds a radio system for the personal airplane must build it so that new functions may be added to the system as required in more or less the sequence that a personal plane owner expands the use of his airplane, keeping cost and weight to a minimum. This should not be difficult as the new very-high-frequency assignments make such a planned system much easier to achieve than heretofore.

All personal airplane communications will be very high frequency, so we should start with the receiver for training plans and the transmitter–receiver combination for personal airplane contact flying. We add the very high frequency range feature when cross-country flying is contemplated, if possible incorporating ranging, and finally the instrument-landing functions.

In conclusion some mention should be made of the vast network of point-to-point communications required to tie together all the other features of aviation communications and provide integrated control.

The domestic airlines alone maintain nearly 50,000 miles of private-line teletype for their own exclusive use to transmit their operating and dispatching messages, reservations, and administrative messages, and the tremendous number of words required to maintain fleets of airplanes. Only through such communications can their operations be conducted efficiently.

The Civil Aeronautics Authority in addition operates over 40,000 miles of private-line teletype networks to integrate its domestic system of navigational aids, and to make available the large quantity of meteorological data required by aviation.

In international aviation, this problem is not solved so adequately as wired teletype does not exist. It is necessary to handle this volume of messages by radiotelegraph until radio-teletype is available, at which time it is hoped the changeover can be made to this method of transmission and greatly speed up and increase the word volume which can be transmitted over present radio circuits.

Transmission Networks for Frequency Modulation and Television

HAROLD S. OSBORNE
FELLOW AIEE

AMONG THE MANY postwar developments to which we look forward, frequency modulation and television are outstanding in interest and in promise and there is widespread confidence among broadcasters and others concerned that the future will see a great expansion in these arts.

It is recognized that one requirement for such large development will be the establishment of satisfactory networks by means of which the best programs can be made available to a large number of broadcasting stations, and the cost of providing such programs can be distributed over a large base. This is a natural conclusion from the experience with standard broadcasting which makes regular use of four national networks and a number of smaller networks provided by the telephone companies of the country. This article discusses plans of the Bell System Companies for making available transmission networks for frequency modulation and television and, as closely related to this, it includes a brief discussion on local transmission circuits, within a city, for both of these developments.

LOCAL CIRCUITS FOR FREQUENCY-MODULATION TRANSMISSION

Studio transmitter circuits for frequency-modulation broadcasting stations, at the present time and for the most part, use ordinary telephone wires in cable which are provided with special equipment. The Federal Communications Commission standards of good engineering specify that such circuits should transmit satisfactorily a band of from 50 to 15,000 cycles. Bands of this width have been provided for some of the standard broadcast circuits so that the introduction of this requirement for frequency-modulation broadcasting stations does not impose any severe new condition on the telephone circuits.

For this purpose the telephone-cable pairs are equipped with amplifiers at intervals averaging about eight miles. The circuit is equalized carefully throughout the frequency range to be transmitted and, in some cases, special steps are taken to reduce the noise level.

Of the 46 commercial frequency-modulation broadcasting stations in operation today, 40 are using telephone-wire lines. However, frequency-modulation stations often are placed on high points and there are a few places where the location selected is not readily accessible to telephone wires. In these cases radio is used to provide the connecting link.

INTERCITY NETWORKS FOR FREQUENCY-MODULATION BROADCASTING

At the present time those frequency-modulation broadcasting stations which are receiving network programs, generally

In the past the telephone companies have played an important role in the transmission of television and frequency-modulation broadcasts. This article discusses their contributions to date and their program to provide facilities for the expected postwar boom in these arts.

speaking, are connected to the networks used by the standard broadcasting stations. These networks usually transmit a frequency band of 5,000 cycles.

Because of the high quality associated generally with frequency-modulation broadcasting, there has been some discussion of the probability that future networks for frequency-modulation broadcast stations should transmit a broader band of frequencies. Often a band of from 50 cycles to 15,000 cycles is spoken of as desirable, corresponding to the band now transmitted over local studio-transmitter circuits.

The transmission of this broader band, or any fraction of it that may be decided upon by the frequency-modulation broadcasters as desirable, does not offer any serious problem to the telephone companies. This results from the fact that they already have a very extensive network of lines transmitting bands of 15,000 cycles or more all over the country for multiplex telephony. Generally speaking, on routes already equipped for transmission of these broad bands of frequencies, additional circuits can be equipped as required without difficulty. Furthermore, the continuing demand for additional telephone circuits is resulting in a continued extension of the mileage of telephone routes so equipped.

TYPE-K CARRIER SYSTEM

This favorable situation has come about through the continued development and extension of use of "carrier" telephone systems to provide multiplex telephony for the long-distance telephone business. Such systems have been used to an increasing extent by the telephone companies during the past 20 years and during the past two years more than 80 per cent of the large increase in long-distance telephone circuits has been by the use of such systems.

The general features of carrier telephone systems are well understood. However, it is of interest to review briefly the system applied to telephone cables (the *K* system) which is particularly important in connection with the future extension of frequency-modulation networks. This system is used on ordinary cables consisting of pairs of 19-gauge insulated wire. Figure 1 shows diagrammatically the frequency arrangements of the multiplex telephone channels. A four-kilocycle band is assigned to each voice channel. Twelve such bands are packed closely together in a 48-kilocycle space between 60 and 108 kilocycles using single-side-band technique with suppressed carriers. This 12-channel band is a basic feature in a number of carrier systems. When the transmission is to be over paired-cable conductors, the band is reduced by a second modulation to the frequency range 12 kilocycles to 60 kilocycles as indicated in the diagram.

A similar system is used for transmission over open wire but with somewhat different frequency allocation and with provision for transmitting over the same pair

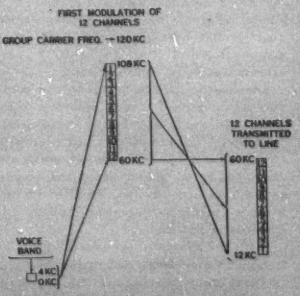


Figure 1. Frequency translations in carrier-telephone-terminal equipment (type K) for paired-conductor cables

Essential substance of a paper presented before a joint meeting of the Washington Sections of the AIEE and the Institute of Radio Engineers, February 13, 1945.

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of conductors, at different frequencies, the two blocks representing transmission in opposite direction.

Bell Telephone Laboratories have completed the development of two arrangements for using these broad-band carrier systems for program transmission. One arrangement consists of an 8,000-cycle single-side-band system arranged to displace three telephone channels and to permit the continued operation of the other nine. An 8,000-cycle band was chosen for this system because it matches the 8,000-cycle program-transmission system already available over many thousands of miles of telephone route.

The second system which has been made available is a double-side-band system using the space normally occupied by 12 message channels. This system can give any band width up to 15,000 cycles, or even more if it should be desired.

FREQUENCY-MODULATION NETWORKS

The availability of these systems gives the telephone companies a wide degree of flexibility in meeting future requirements for frequency-modulation broadcasting stations. There is, first of all, the possibility of networks of the type now commonly used for standard broadcasting transmitting a band of about 5,000 cycles. There is a broader band system transmitting about 8,000 cycles which has been a standard offering of the telephone companies for about ten years, but which, so far, has received little use. The facilities already in the telephone plant and the adaptation of broad-band multiplex telephone systems for the use of this system make it possible for the telephone companies, on reasonable notice, to provide networks of this type. There is also the 15,000-cycle type of circuit which already has been designed for routes transmitting Type-*K* carrier systems and which readily can be adapted for transmitting over other types of broad-band systems.

The situation may be summed up by saying that with the relaxation of war restrictions, the frequency-modulation broadcasters should be able to receive nation-wide networks meeting any transmission requirements which they may select as desirable.

Figure 3. Cable with six coaxial units and layer of 19-gauge quads

TELEVISION TRANSMISSION WITHIN CITIES

For television transmission, as for frequency-modulation broadcasting, short circuits within cities can use specially equipped ordinary telephone pairs. The special equipment and other rearrangements necessary in the case of television transmission are illustrated by Figure 2 which shows diagrammatically a circuit of this type about 1.6 miles long in New York City. In order to get a direct route and use the maximum sizes of conductor available it was necessary to open cables and make special splices between subscriber cables and trunk cables as indicated. The subscriber cables were opened at other points to cut off bridged taps which seriously would affect the high-frequency transmission. Amplifiers were installed at both ends and at one intermediate point. With those amplifiers equalizers were installed and, at the two ends of the circuit, predistortion and restoring networks. The equalizers were adjusted on the basis of over-all transmission tests throughout the range of frequencies to be transmitted and measurements were made to determine that the noise was sufficiently low. The over-all transmission loss of the circuit at four megacycles, without amplifiers, would be approximately 100 decibels. Upon completion of the work, and with the amplifiers and the equalization installed, the circuit transmitted a band of four megacycles with zero over-all loss and was equalized throughout the band, both for attenuation and for phase, to limits that provide satisfactory transmission.

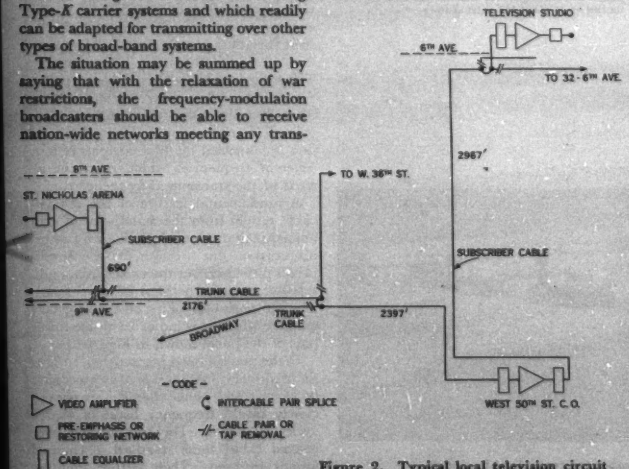

Figure 2. Typical local television circuit

The telephone companies have been providing a few circuits of this type for about five years. An alternative to using ordinary telephone pairs is to use coaxial cables or special shielded pairs. Both of these types are in use. Pulling a small cable meant exclusively for television into a city duct is a relatively extravagant use of duct space, and such special conductors can be provided most economically if they are included in full-size cables along with pairs provided to meet telephone requirements. To do this, however, requires long-range planning, as telephone cables generally are designed to meet prospective requirements for a number of years.

TELEVISION TRANSMISSION OVER INTERCITY CIRCUITS

The continued search of the telephone companies for increased efficiency in use of conductors for multiplex telephony has led to the development of a system suitable both for multiplex telephony and for television transmission. This is commonly spoken of as the coaxial-cable system because of the form of conductor used.

The 12-channel multiplex telephone system already has been described briefly. This system is used throughout the country on ordinary telephone pairs and occupies a band of frequencies from 12,000 to 60,000 cycles.

Placing still more channels on one pair would mean using still higher frequencies. As the upper limit of the frequency range is raised, the difficulties of providing suit-

able transmission paths become increasingly formidable. One major difficulty arises from the necessity of reducing to truly microscopic proportions the transfer of energy from one pair of wires in a cable to any other. With 100 or more pairs of wires packed tightly together, this is a great task, even at frequencies up to 60,000 cycles, and it becomes progressively more difficult as the frequency range becomes higher. While it is a matter of judgment as to just how far to go, it is evident that telephone pairs of a conventional design are not adapted for the transmission of very broad bands of frequencies over long distances.

For a solution of this problem shielding naturally is indicated. However, if we are to use a shielded conductor, the logical thing is to ignore the traditional form of telephone cable and design a conductor suitable for the transmission of very high frequencies. Consideration of this problem leads naturally to a very simple and classical form of conductor; the coaxial unit consisting of a cylindrical conductor surrounded by a cylindrical shield which also acts as a return conductor. The space between the two is, as far as possible, gas insulated to minimize losses at high frequencies.

In the solution of the problem the aforementioned conductor design was selected. Through a very extensive development process means were worked out for building such conductors economically on a large scale and of such design that several could be grouped together under one lead sheath and used under practical conditions.

The width of frequency band which can be transmitted over such conductors is primarily a matter of the design possibilities of associated equipment. The equipment now in use with the coaxial system is capable of transmitting a frequency band up to about 3,000,000 cycles. With this equipment we find it possible to transmit 480 telephone conversations simultaneously without mutual interference.

TECHNICAL FEATURES OF THE COAXIAL-CABLE SYSTEM

Some of the interesting technical features of the coaxial-cable system can be noted by reference to a few figures. The cable itself is made up as indicated by Figure 3. Generally speaking, a number of coaxial units and a number of ordinary paper-insulated paired conductors are included under the same lead sheath, the number of each being determined by the expected future service requirements to be taken care of by the cable over a number of years. This particular cable contains six coaxial units and 42 pairs for telephone use and is a section of a cable installed between Terre Haute, Ind., and St. Louis, Mo., to increase the telephone facilities on that portion of a main route between New York, N. Y., Chicago, Ill., and St. Louis.

These cables generally are placed underground by the use of a plow train. Three caterpillar tractors connected in tandem are followed by a rooter plow which prepares the ground for the cable, then by a fourth tractor backed by the cable laying plow, and finally by one or more trailers carrying reels of cable. This entire equipment is connected as a single train and as it advances the cable automatically is fed off the reels through the plow and buried at a depth of 30 inches or more in the earth (see Figure 4).

Essential elements of the system are the amplifiers which are placed in the cable at intervals of about five miles.* One such amplifier is indicated in Figure 5. It is a three-stage amplifier giving about 50-decibel amplification at three megacycles, provided with negative feedback, and so free of distortion that the currents of hundreds of different telephone channels covering a frequency band of 2,000,000 cycles can be transmitted across the country through hundreds of these amplifiers without mutual interactions sufficient to cause any interference.

* Subsequent to the writing of this article, a somewhat larger coaxial unit has been introduced which uses repeaters at about eight-mile intervals and main repeater stations up to about 150 miles apart.

Figure 5. Coaxial amplifier

Figure 6 shows the assembly of two amplifiers and auxiliary equipment in a case suitable for connection into a pair of coaxial units at one point. The two amplifiers are the two square black boxes near the top of the case. Above them is automatic regulating equipment designed to counteract the variation in loss caused by variations in temperature of the cable. These regulators make a very interesting application of thermistors whose temperature is controlled by the flow of a pilot current over the circuit and which, by their variations of resistance with temperature, provide automatic compensation. The compensation at these repeater points is supplemented at main repeater stations 50 to 80 miles apart by a supplementary over-all compensation. This compensation is controlled by pilot currents of four different frequencies which represent all parts of the transmitted-frequency range.

A fundamental feature of the coaxial-cable system from the standpoint of economics is that the cable is its own power-transmission line. Power for the amplifiers is provided over the cables from main repeater stations, perhaps 80 miles apart. The equipment for taking off the necessary amount of power is indicated in the lower part of the panel shown in Figure 6.

In the discussion on transmission circuits for frequency modulation the procedure by which 12 telephone channels are packed closely into a frequency band of 48,000 cycles is shown. For transmission over coaxial cable, these standard 12-channel groups are used. Their further grouping

Figure 4. Plow train burying cable for coaxial-cable system

to pack them into the coaxial cable is indicated in Figure 7. A standard supergroup of 60 channels is created by closely packing five of the 12-channel groups into a 240-kilocycle band. This supergroup is translated further into various parts of the frequency range, as indicated in the figure, for transmission over the cable. Thus the 480 circuits occupy a range from 64 kilocycles to a little over two megacycles.

The frequency range used with the same system for television transmission is somewhat different as shown in Figure 8. The phase-equalization requirements are so exacting for television transmission that it becomes desirable to raise the video band by about 300 kilocycles, thus avoiding a very complicated equalization problem at frequencies lower than that. On the other hand, the upper range of the transmitted band can be extended to about three megacycles without exceeding noise levels and other limits satisfactory for television transmission. The double-modulation process by which the video signal is raised into this range is indicated in the figure.

The effective band width for transmission of television with the present equipment is 2.7 megacycles. This is less than the four-megacycle band which is the present standard for television. It is, however, a temporary situation and tests in 1941 over an 800-mile line indicated that it gave satisfactory results for the state of television at that time.

FUTURE DEVELOPMENTS

When the war suspended operations in this field, development work was under way on the design of a broader band coaxial system, making available at least four megacycles for television. One system that was under development will provide a band of seven megacycles or more. With this system it should be possible to provide for television whatever band is desired by the television industry, either four megacycles or more or less, and to use the rest of the band for multiplex telephone channels. With further advances in technique in the future, it is to be anticipated that a system permitting still broader bands over coaxial cables can be developed if desired.

Another promising looking method of providing for broad-band transmission systems for multiplex telephony and for television is the microwave-radio-relay system. This system carries over into radio technique one of the fundamentals of long-distance wire telephony, namely, the establishment of repeater points at frequent intervals along the circuit.

The Bell System has made arrangements for a development trial of a microwave-relay system between New York and Boston, Mass. Approval of the Federal Communications Commission already has been obtained for the project and work will proceed as soon as possible. For this trial seven intermediate relay repeater points will be used. Figure 9 shows the locations and heights of these intermediate repeater points. Height is important because the radio circuits will operate on visual paths. You will note that the maximum distance between repeater points is 35 miles and the average is about 30 miles.

The Federal Communications Commission has assigned to these experimental frequencies of about 2,000 megacycles, 4,000 megacycles, and 12,000 megacycles. This trial will be used as a method of determining practically the possibilities of this type of system in the present stage of development or, more exactly, in the state of development which can be brought about soon with intensive additional work.

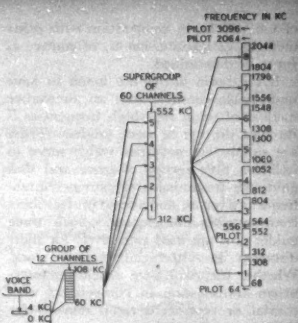

Figure 7. Frequency translation in carrier-telephone-terminal equipment for coaxial cable

The development of a system of this type suitable for long-distance service involves the solution of many problems. While many of the elements which make up the system are already well developed, further extensive work will be required to organize them into a system suitable for this purpose. As in the case of wire circuits the individual repeaters must meet very exacting requirements in order that the cumulative effect of the transmission characteristics on a long-distance circuit will not exceed limits which are suitable for the over-all characteristics of such circuits. To meet such requirements it will be necessary to achieve in the ultra and superhigh-frequency ranges, where these systems are to operate, refinements in amplifier design. To do this doubtless will be the same kind of painstaking task that has been carried through in the development of amplifiers for the coaxial-cable systems operating at lower frequencies.

Moreover, many practical problems must be solved to provide a system of satisfactory reliability. Simple illustrations of this are the design of antenna supports having ample rigidity under storm conditions and the protection of the antennas from sleet and ice.

What the outcome of the experiments will be no one can say. We all look, however, with admiration at the great strides which were made during the war in the development of apparatus using ultrahigh and superhigh frequencies and it is the general expectation of radio engineers that, in the long run, such a system will be made practical. What its proper field

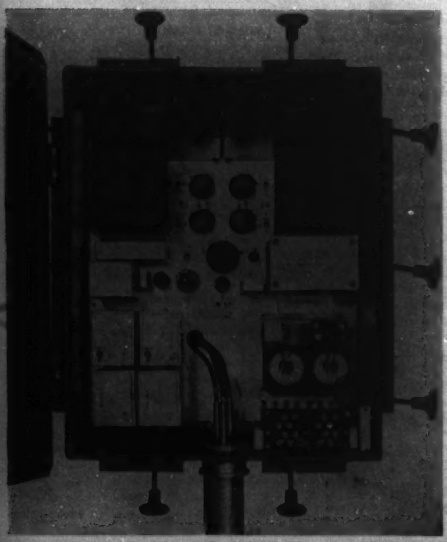

Figure 6. Equipment at coaxial repeater station

of use will be in competition with other methods of transmission is, of course, as yet to be determined.

If the radio beams are found to have undesirable characteristics an alternative method of using superhigh frequencies is through the use of wave guides. These are simply hollow pipes which serve to isolate a little section of space and thus guide the transmission of extremely-high-frequency waves, and also to protect them from outside interferences. Such wave guides now are used extensively for short distances in ultrahigh-frequency work. Whether they will have a field for inter-urban transmission in competition with coaxial or repeatered radio remains for the future to determine.

PROGRAM OF THE BELL SYSTEM FOR THE CONSTRUCTION OF FACILITIES FOR VERY-BROAD-BAND TRANSMISSION

Where and when will the Bell System Companies have available intercity television-network circuits of the types just discussed? Here the situation is somewhat different from that for frequency-modulation networks as there is not a large network of suitable routes already established. However, such a network is being built rapidly as a part of the Bell System program for meeting additional requirements for long-distance telephone circuits.

A section of coaxial cable between Stevens Point, Wis. and Minneapolis, Minn., a distance of about 200 miles, has been in service since 1940. Coaxial cables have been installed between New York and Washington, D. C., Terre Haute and St. Louis, Atlanta, Ga., and Jacksonville, Fla. At the moment such cables are under construction between Atlanta and Meridian, Miss., and between Washington and Charlotte, N. C.

From a telephone standpoint the most important feature of this program is a second transcontinental cable route from Washington through Atlanta across the southern part of the country to Los Angeles, Calif. The completion of the entire route will be pushed as rapidly as possible. The company hopes that, in about a year, the cable will be in place at least as far west as Dallas, Tex. Other main features of this program are the connection of Washington and other Eastern Seaboard cities to Chicago and St. Louis to supplement existing cables and a new cable route from St. Louis south to New Orleans, La., intercepting the transcontinental route at Jackson, Miss.

While this plan no doubt will be modified in some details as it progresses, it is getting a big start in 1945 and it is expected that within about five years something substantially similar to this will be in operation providing long-distance telephone circuits. On these routes coaxial cable is the best method of providing the additional telephone circuits urgently needed to take care of growth.

Coaxial cable can be provided for all of this initial program. However, the radio-relay system will be used to any extent that may be found advantageous. The New York–Boston section is expected to consist of the experimental radio-relay system. The extent to which that system may be applicable to other sections of this initial network and to the additions which will follow in subsequent years cannot be predicted at this time. It is planned to use for each part of the network that type of system which is best, taking into account both service standards and economies.

It is anticipated that following the completion of this program, very-broad-band transmission facilities will continue to be placed on other routes as necessary to meet the service requirements of the telephone companies. This expanding network of very-broad-band transmission facilities will form an excellent basis for the development of nation-wide television-transmission networks when the art develops to such a point that these become desirable. Once a route is established additional requirements, either for telephone or television, can be established by the installation of additional equipment using in the case of cables, spare coaxial units provided to take care of future service requirements.

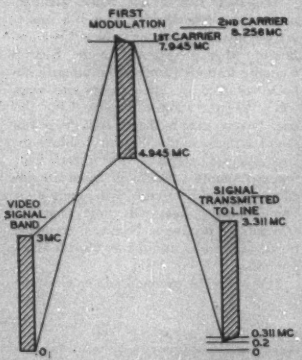

Figure 8. Frequency translations in television-terminal equipment for coaxial cable

NETWORK OPERATION

With the extensive development of frequency-modulation and television broadcasting, it is to be expected that transmission circuits of the types which have been described, or of other types which may be developed, will be connected to form great networks as is done now with the transmission circuits for standard-frequency broadcasting. The experience of the telephone companies in the operation of the present nation-wide networks shows that such operation involves many problems in addition to those of providing the circuits themselves. Much of this experience is indicative of the problems to be anticipated in the provision of networks for either frequency-modulation broadcasting or television. Therefore, a brief review of some of these problems is of interest.

Figure 10 shows the principal routes covered by the present program-transmission networks. A large part of the 135,000 miles of program circuit is associated with four nation-wide networks, but, in addition, there are a number of smaller networks. A single nation-wide network may connect 250 broadcasting stations with 20,000 miles of circuit.

Important features of network operation are the following:

1. To be suitable for network operation the transmission circuits must be kept at a very high level of maintenance. Interruptions or

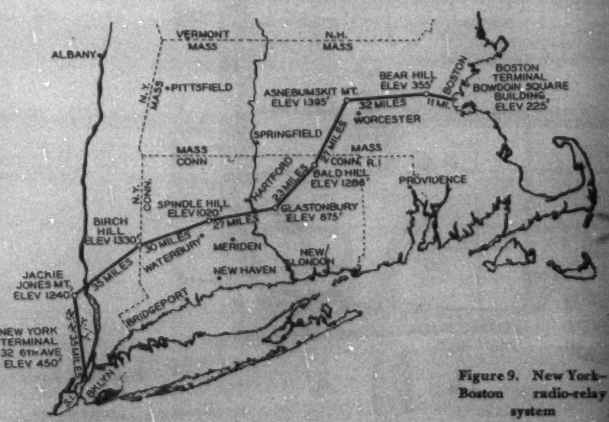

Figure 9. New York–Boston radio-relay system

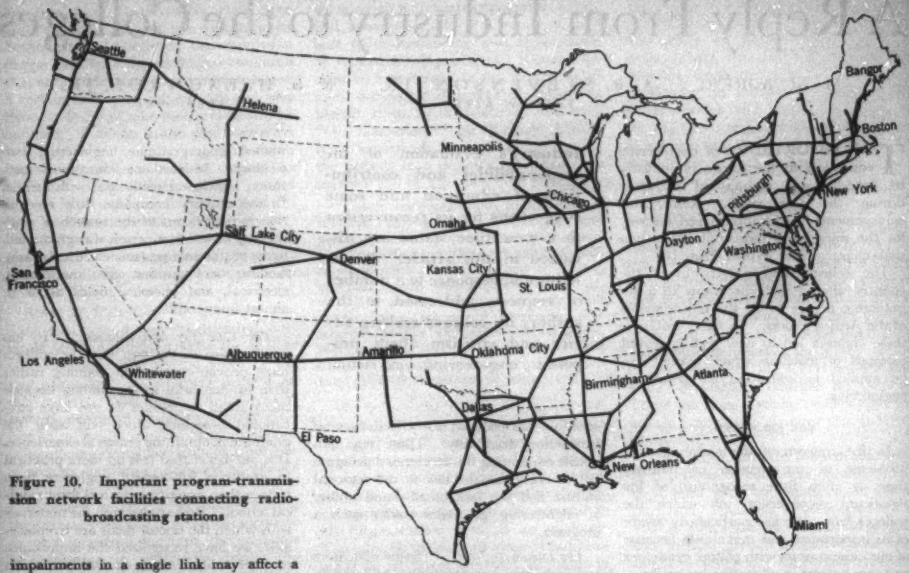

Figure 10. Important program-transmission network facilities connecting radio-broadcasting stations

impairments in a single link may affect a large part of the entire network. Whether a nation-wide network is made up of wire lines or radio-relay circuits or part of each, there is a great deal to be maintained. The coaxial cable involves cable and equipment all along the route and repeater stations, including equipment and sources of power at intervals of from 50 to 80 miles. The radio-relay system avoids the maintenance all along the route, but probably will involve repeater stations with sources of power and with their associated antenna structures at intervals of about 30 miles. In any case, a comprehensive and highly trained maintenance force is necessary for continued satisfactory operation.

2. The standards of design applied to each link of the network must be much more severe than would be necessary for the operation of the single link by itself. Each link must be designed so that it will work satisfactorily with many other links in a wide variety of connections. The distortion effects are cumulative and the maximum distortion between any two points of the network must be kept within satisfactory limits.

3. Throughout the country bridging equipment must be installed to enable the reception of a program over one link of a network and its transmission at that point to a number of others with proper transmission levels on each. One bridging point may supply as many as ten branches of a network.

4. Arrangements must be provided for instantaneous and often very complicated switching to rearrange the networks for successive programs. Much of this switching is done at the studios and a great deal is done at key points of the telephone system. In some places where the switching problem is complicated, arrangements are provided so that while one program is in progress the connection of the network for the next program is preset upon an alternative switching panel without interfering with the program. Upon the receipt of the proper cue, the attendant, by throwing a single remote-control key, instantaneously completes the rearrangement.

5. At key points attendants monitor the programs continually. Other attendants make a series of routine tests and make adjustments of level and other adjustments as necessary to insure the continued operation of the network. The amount of this work is equivalent to the full time of about 400 men. The total involved is, however, much larger, as many men spend only a part of their time on this type of work.

6. To assist this operating force in making their work most effective, key points are connected by a network of 70,000 miles of telegraph circuits devoted entirely to network operation.

7. At times of emergency the affected sections of network must be re-established in the briefest possible time by stand-by circuits and by spare equipment or by the use of alternative routes. At such times the existence of a large program-transmission network forming a part of a much larger telephone network is of great service importance. Numerous alternative routes are available and stand-by circuits and spare equipment are used in common to meet the needs of any individual network. Also, certain types of facilities designed for telephone-message service can be used.

This is a very sketchy outline of a number of diverse problems but it is sufficient to indicate that the operation of nation-wide television-transmission networks will involve a highly trained nation-wide organization and much equipment.

CONCLUSION

It is believed that the telephone companies can face any new requirement which may be laid on them by the development of frequency-modulation broadcasting and television with confidence because of their wide experience in handling nation-wide communication networks. The Bell Companies have in service 10,000,000 miles of long-distance telephone circuits terminating in 2,400 switching centers. They operate 135,000 miles of program-transmission circuits including the four nation-wide networks. These two services are incorporated in the same plant and handled by the same operating forces. The operation of these services provides a fund of experience which should be useful in the design, construction, maintenance, and operation of networks for either frequency-modulation or television transmission.

The telephone companies will be helped greatly in their efforts to give the best possible service to these new industries if they can take account of the prospective requirements for new transmission networks at the time they design broad-band extensions to the present great network of telephone lines. They, therefore, welcome from all who are interested in the application of these new arts information as to the development of their requirements and wish to receive these data as soon as possible.

A Reply From Industry to the Colleges

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Industry's evaluation of the responsibilities and contributions of education and some suggestions for its reconversion to a peacetime status are discussed in this article. It was written in response to a number of requests addressed to the authors by colleges seeking advice and criticism about proposed engineering curricula.

THE IMPORTANCE of engineering education to the future of industry in America was emphasized strikingly during the war years. Remarkable achievements in education paved the way for the miracles of industrial production that characterized World War II.

The colleges and universities of the country altered their programs to a remarkable degree to fit the requirements of the Armed Forces. In many instances these changes led to new and improved methods of teaching which readily can be applied to education for peacetime engineering.

THE JOB AHEAD

In the concern of the nation for the problems of reconversion of industry there is often little recognition of the significant reconversion job which the colleges face. We are particularly aware of its importance and magnitude because of our close contact with college graduates and our interest in education generally.

In recent months colleges have been asking the assistance of industry in planning postwar college curricula. Although few men in industry have ever taught in a college or university, many have had considerable contact with the college graduates who are hired annually by industrial concerns. Industry is rightly realizing the importance of education in engineering and welcomes an opportunity to discharge a part of its responsibility in this field by co-operating with the colleges in studying postwar curricula.

The Accelerated Schedule. There is grave danger that some colleges and the public generally may believe that an accelerated college program is superior to the prewar college schedule. Experience with those graduates employed in the last two years leads us to believe that the engineering graduate of an accelerated program is limited, compared with his prewar predecessor, in his ability to analyze engineering problems from fundamentals.

Students enter college much earlier than usual, with the result that few of them are sufficiently mature or emotionally adjusted for the college experience. Elimination of most free time in the accelerated schedule has reduced the effectiveness of instruction drastically. Those who advocate continuing the accelerated program fail to recognize the loss to the national culture and the lack of all-round ability of engineering graduates under such a program.

The Immediate Need. Some educators and industrial representatives will see in the reconversion facing the colleges an unusual opportunity to make sweeping changes. Although needed changes should be introduced wherever possible, we should recognize that the primary emphasis is upon the necessity of returning to basic college curricula as rapidly as possible. Except for men returning from the services, a negligible number of engineers will be available to industry in the next few years. Nothing should delay an immediate return to regular college programs in order that this barren period may be as brief as humanly possible. Any changes that are to be made, therefore, must not delay this return.

PRIMARY EMPHASES IN THE CURRICULUM

Basic Engineering Fundamentals. Engineering education in college must be concerned with engineering fundamentals rather than with specialized design. The war showed us that radically new designs usually must be based on the fundamentals of engineering rather than on previous design. It is far more important, therefore, for the college graduate to have a thorough understanding of all the fundamentals underlying engineering rather than detailed knowledge of any specific design or device. For example, a thorough understanding of such fundamentals as Newton's laws is of far more value in the solution of general mechanics problems than a host of specialized formulas.

Many will take exception to these beliefs, pointing out that widespread acceptance of them would lead to a single unified undergraduate engineering curriculum. At least one educational institution has done exactly that with success. In the authors' company, little recognition is ever taken of the branch of engineering in which a person was graduated, as the requirements of any electrical manufacturer so combine the mechanical, electrical, and chemical fields as to be almost inseparable.

The Case for Specialization. It has been argued in the past that the colleges must provide specialized training rather than fundamental understanding because many small companies do not have educational programs which will assist the graduate in obtaining practical experience. It is our belief that it is no more practical to graduate full-fledged engineers from college than practicing doctors from medical school. Perhaps because the materials with which the doctor deals are irreplaceable, we have recognized the importance of interneship earlier in this profession than in engineering. It is nonetheless essential to the successful training of outstanding engineers.

Some attempt has been made to recognize such an interneship or apprenticeship by the provision of some states, notably New York, for an "engineer-in-training" level of the professional engineers. Such an apprenticeship means that a small company without even a single good engineer who is capable of educating newer men cannot hope to supply this need directly from the colleges but must employ from some other concern an older engineer who has had both education and practical experience. In other words, there is no substitute for apprenticeship in the best sense of the word in engineering as well as in mechanical trades.

Stimulating Ingenuity. A second equally important consideration which must be borne in mind in discussing college curricula is the stimulation of the native ingenuity of undergraduates. During the war period, students usually were not encouraged to think for themselves in the rush of absorbing detailed knowledge in a rather limited field. We believe that emphasis on engineering fundamentals and ingenuity go hand in hand to develop a successful engineer. To encourage the ingenious student further, the curricula of the future should provide opportunity for the design and construction of ingenious electrical and mechanical devices.

The educational purpose will be better satisfied and more such projects can be

Essential substance of an article endorsed by the committee on relations with industry of the Society for the Promotion of Engineering Education and published in the *Journal* of the SPEE and in *Mechanical Engineering*, August 1945.

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provided by the colleges if such devices are small and simple rather than large and complex. At least one college in the Southwest has scheduled this type of a design class with the additional condition that only students who have demonstrated a certain minimum of ingenuity and who strongly desire to take such a class will be enrolled. Students in the past have often been required to take college design courses regardless of their interest in electrical design. Such design classes seldom have involved actual physical design and development of ingenious devices. We believe that the plans for classes such as that suggested will stimulate interest in design and development to an unusual degree.

Extent of Electronics. It is hardly possible today to discuss engineering curricula without touching upon the subject of electronics. The special needs of the war stimulated an unusual interest in this subject. The need for technically trained personnel acquainted with electronics principles resulted in the inclusion in most engineering curricula of a number of courses specifically designed to answer such a need.

Although training in electronics during the prewar years was probably inadequate to meet industrial demands, the emphasis on education in electronics during the war exaggerated the relative importance of this phase of the electrical industry in the postwar period. In the authors' company, for example, estimates of postwar business indicate that the apparatus lines will still be ten times greater than the communications business. We therefore are vitally interested in maintaining a proper ratio between education provided by the colleges along these two directions.

In general, it is preferable to give the student engineer a broad concept of the complete frequency spectrum, emphasizing particularly the fundamentals underlying the operation of devices at any frequency. Thus, whenever need arises for a fundamental understanding of high-frequency problems, the basic principles are already well understood. In addition to presenting proper technical material, the college also must be prepared to stress the relative importance of communications compared with the other branches of engineering.

Preparation for Citizenship. Many articles have appeared in the technical press in recent months emphasizing the importance of the nontechnical portion of an engineering undergraduate curriculum. There is no doubt that recognition of the more cultural and liberal phases of education too long has been ignored in engineering colleges. Here also, however, there is some reason to advocate caution in the extent to which the nontechnical part is increased. It is beyond question that some engineers adequately prepared technically have found great difficulty in adjusting themselves to industry and developing an active participation in society and community life as a result of their lack of understanding and appreciation of nonengineering subjects. Great care must be experienced in the way in which such subjects are taught if maximum benefit is to be derived. In his book "On Education,"* Sir Richard Livingstone is particularly emphatic concerning the periods in a person's life when such material can be absorbed most usefully:

"That is, you cannot study fruitfully liberal subjects, among them philosophy and politics, unless you know something of life. On the other hand, there are subjects, such as mathematics, which a boy or undergraduate is fully capable of understanding, even if he knows nothing outside the walls of his home, school, or university. For whereas politics and ethics are concrete, mathematics is purely abstract and theoretic and does not spring from life or need experience of life to illuminate or correct it."

We believe that the principal purpose of such subjects as English, public speaking, and art of dealing with others, in engineering curricula should be to acquaint the undergraduate with the importance of these subjects and to develop his appreciation for them as essential to his future career even as an engineer. Too often in the past an attempt has been made to get across a certain minimum of information rather than an attitude of mind. All of these liberal subjects should be taught by a person who has a sincere appreciation for the role of the engineer in society and who can understand fully the engineering point of view. It is only such leadership that can stimulate and impress the young engineering student with the importance and value of such liberal material.

For example, much of the student's antipathy for English can be traced, we believe, to a lack of understanding of the engineering student by his English professor. This point is illustrated particularly well in a recent article[1] by A. M. Buchan. This same article describes the effect of encouraging the professor of liberal subjects to appreciate the relation of engineering to society in these words:

"The professors learn from their students. An interest in technical subjects has been born, and the old literary bias against them is disappearing. A notion of culture as an attitude assumed toward any subject, technical or philosophical, rather than as familiarity with certain arts and books begins to appear, and the teacher of Wordsworth or Thoreau finds himself engaged, and happily, in discussing baking methods or the development of alloys. For the teacher of speech, too, there can be a realization that the orderly description of a coke oven is just as valuable practice as an argument on Fascism."

We also would suggest that, in spite of the modern tendency to depreciate the value of foreign languages in the curricula, there is a real value in the study and mastery of languages other than our own. The study of history, economics, and civics should not be neglected, but in these also emphasis should be placed upon developing an attitude of mind in the student which will make him aware of the engineer's responsibility as a member of society and the large part which he should play in such society.

ADULT EDUCATION FOR ENGINEERING GRADUATES

Recognition of the importance of adult education has increased greatly in the past few years. A quotation from Sir Richard Livingstone mentioned earlier suggests that intensive study of cultural or liberal subjects, such as philosophy and politics, is properly postponed beyond graduation and should be reserved for a later period in the engineer's life when he has had some experience outside the school. There has been a strong tendency for the college graduate to consider his education completed.

The proper attitude toward education as a process of continual growth should be stressed again and again to the undergraduate. He then will recognize that without education there can be no growth, and without growth of individuals there can be no progress. Rarely has a graduation address failed to dwell on this aspect of education. Yet much of the student's previous conditioning in college creates an opposite attitude. The Engineering Council for Professional Development has recognized the need of engineers for adult education, particularly in liberal subjects, and has strongly supported the demand for adequate adult education.

What Has Been Done. In Denmark, "high schools" have been established to provide liberal education for adults. What has been accomplished in this field in this instance is described by Sir Richard Livingstone.

"...the Danish People's High School, should be of peculiar interest to us for it is the only great successful experiment in educating the masses of a nation. It has reached the very classes for which we have done little or nothing. It has taught them to care for subjects like history and literature which seem remote from the man in the street. It has transformed the country economically, given it a spiritual unity, and produced perhaps the only educated democracy in the world. Here is that rare thing in education—an ideal embodied in fact. It is curious that it has excited comparatively little attention among ourselves who are facing the problem which these Danish schools have solved.

"We find it difficult to think of Denmark as a poverty-stricken country lacking in energy or enterprise; but such it was in the early nineteenth century, and its transformation into one of the most progressive and prosperous democracies of Europe was largely the work of the education given in these schools. . . ."

* Quoted by permission of the publishers, the Macmillan Company, New York, N. Y.

A New Area of Engineering Education. We believe that the colleges and universities of the country should take the lead in providing adequate opportunities for education in liberal subjects for engineering graduates. In many cases this may involve considerable rearrangement of schedules and programs to accommodate evening classes. The teachers of these classes also will benefit greatly because, for the first time, they will have students whose "experience of life" is fully as great as their own. The class members thus will contribute much to the instruction of the class. The value to the nation and to the individual adult student far outweighs the difficulties which must be overcome to provide such opportunities.

THE MOST IMPORTANT FACTOR IN EDUCATION

Although revision of engineering curricula is a laudable undertaking, it is almost useless to consider such changes apart from the teaching staff. The failure to stress the significance of outstanding teachers in college education is to neglect the most important factor in education. No opportunity should be overlooked to attract outstanding engineers to the teaching profession.

The question has often been raised as to whether there is a wide difference in salary levels between industry and education which deters a young man from considering a career in education. The problem is well illustrated by a recent comment by Dean C. J. Freund of the University of Detroit:

"There are such (ideal professors) but most colleges cannot afford them. It has been my experience that after an outstanding teacher has been developed, he will someday be a luncheon or dinner companion of the president of a manufacturing or industrial corporation. He impresses the president who very soon thereafter offers the professor or assistant professor a salary which is fabulous according to college standards. The professor may be an idealist and he may be devoted to his university, but there are limits even to generosity and heroism."

The Contribution of a Great Teacher. Many schools undoubtedly never would be able to employ a full complement of outstanding teachers at adequate salaries. Such schools would find it profitable to make use of undergraduate leaders, selected for their brilliance and teaching ability, in order to obtain maximum benefit from the really few born teachers which the college could hire.

"A great teacher is a man whose personality is so attractive and whose character is so fine that by unconscious tuition he wins the admiration and lifelong devotion of his students and all unconsciously influences their ideals and molds their characters so that they are forever after better men for having sat under him. There is no substitute for the inspiration and guidance which such a man can contribute."[2]

Wherever there are great men, there is so often a great teacher behind them. There is nothing more important than teaching. There are many outstanding teachers in the colleges now; their numbers must be increased. We must have the best and most capable men in the nation guiding the education of youth.

LEADERSHIP—A PRESSING NEED

No discussion of college education would be complete without mention of leadership. America long has been noted for its educational system, in particular, for the high level of the average intelligence of its citizens. In our desire to improve the average intelligence, we have more and more neglected the brilliant individuals. We must recognize that the contributions to society of an Edison, Marconi, or Alexanderson are far greater than those of scores of John Does. Without depreciating the necessity for mass education, we must in the future concentrate on developing an equally good system for educating the outstanding individuals.

We have great interest in the proposal that undergraduate leaders be selected to assist the regular professors. These carefully selected young leaders, if given proper freedom, could do a much better job of stimulating the students than some of the present instructors who remain on the college pay rolls without promotion for several years. The average pupil thus simply would go through the classes in the present manner, the outstanding student would get the extra opportunity, responsibility, and incentive of teaching a younger class. In addition, the substitution of these undergraduate leaders for regular instructors would release sufficient funds to hire a few really brilliant outstanding professors. Such men would be required to have the ability of working closely with the undergraduate leaders, stimulating and inspiring them, yet making each responsible for his class.

THE AIMS OF EDUCATION

There are then these principal goals toward which the colleges should continue to strive: A stronger emphasis on broad engineering fundamentals; an appreciation of the role of the engineer in society for all college students; and the creation of leadership of a high order. The degree to which we can attain these objectives will determine the future of engineering and of all America.

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Unorthodox Deck-Edge Elevators in Service

The United States Navy hurled its carrier-based bombers and fighters against the Japanese by means of a unique "deck-edge" elevator that whisks planes up the outside of the ship to the flight deck in a matter of seconds. This was revealed recently by the Westinghouse Electric Corporation. Now being installed on the Navy's new fleet of "Midway"-class supercarriers, the unorthodox new elevators secretly have been in battle service in every major task-force operation in the Pacific.

The deck-edge elevator speeds battle action aboard the carriers because it enables plane-handling crews to keep the central-flight deck cleared of incoming planes as fast as they land. As the 50-ton platform is to one side of the flight strip, landed planes can be whisked aside, out of the flight area, with a minimum of handling. During take-offs, too, it permits faster delivery of planes from the hangar deck and prevents planes awaiting take-off from "bunching up" around the elevator openings, as they did when only the bow- and stern-deck elevators were available for delivery from below.

Thirty-four feet wide and 60 feet long, the platform is hung "outboard" over the sea at the edge of the flight deck, opposite the carrier's superstructure. This platform is built of welded pipe and, in use, carries a towing tractor and the handling crew. Because the carriers themselves were designed to permit passage through the locks of the Panama Canal, the 34-foot wide elevator platform is mounted so it will fold up and not strike the side of the canal locks. The platform is lifted and lowered by means of eight $1^1/_8$-inch steel cables which pass over a series of direction-changing and leverage-multiplying sheaves, or pulleys, and are finally attached to either end of a huge hydraulic piston and cylinder assembly, which is the simple "engine" of the system. The piston of the engine is activated by oil pressure led into the cylinder from a pair of compression tanks, where two 150-horsepower electric motors, operating variable-stroke pumps, maintain oil pressure at a constant 850 pounds per square inch. As only part of this pressure is required for a single trip of the elevator from the hangar to the flight deck, the 300-horsepower total power available from the pump motors is the maximum power drain on the ship's electric system at any one time for the operation of the elevator. The use of oil under pressure also enables the elevator to make one complete round trip on "stored" energy even if the motors and controls are put out of action. Thus, if damage occurs while the elevator is loaded, its planes can be brought to the hangar deck, and the elevator returned to the flight-deck level.

Statistical Methods in Quality Control

VI. Charts for Go-and-No-Go Inspection

A method of analyzing the results of go-and-no-go inspection in order to judge whether or not the best results are being obtained on a given job is presented in this article.

STATISTICAL METHODS for control of quality of manufactured products are applied effectively and easily in analysis of test results from go-and-no-go inspection. The purpose of this kind of inspection is to determine whether or not individual units of product meet engineering tolerances, that is, merely whether they are good enough to pass. Generally, no further information about the quality characteristics is sought in this type of inspection.

The results from go-and-no-go inspection may be analyzed best by control-chart technique, the steps in which analysis are:

1. Tabulate for a reasonable time the number of units of product inspected each hour, or each day, the number rejected in each period, and the fraction defective for each period (see Table I).

2. Plot changes in fraction defective from hour to hour, or day to day, in chronological order on a control chart (see Figure 1).

3. Judge by means of control limits whether such changes as occur in hourly, or daily, fraction defective reasonably may be expected to be the result of chance alone (see Figure 1).

The methods of carrying through these three steps are discussed in the following in connection with the inspection of motor end shields.

In any mass-production job, inspection stations are set up at the critical points in the manufacturing process: on certain important parts, at subassembly, and at final assembly. At these inspection stations, units which fail to meet specified requirements are rejected. To inspect should mean more than just sifting the good units from the bad; data regarding the fraction defective at such inspection stations are an index of quality and, by applying statistical methods to these data, conclusions can be drawn as to how well the job is controlled.

On a certain operation (machining a motor end shield) the average fraction defective over a period of 20 days was 0.05. The question then came up, "Is this the best we can do with our present method of machining the motor end shield?" This question can be answered definitely through proper analysis of the variations in the "fraction defective" during each of the 20 days. Control-chart methods will indicate how much variation is likely to occur because of chance (that is, when there are no definite troubles or difficulties). By this means we can tell whether this job is as good as can be expected.

Definite control limits (within which the daily fraction-defective results should vary if there are no definite troubles affecting the job) first are established. If the variations in fraction defective are within these limit lines, we can say that we are getting the best results or, in other words, that the job is under control. If variations are beyond the limits, we are not getting the best results; the job is out of control.

In the case of the motor-end-shield job, during 20 days there were 1,000 (or five per cent) defective units in a total production of 20,000 units. The actual daily results are indicated on the control chart (Figure 1). We want to know what variation in the daily per cent defective can be allowed and therefore proceed as follows:

1. The average fraction defective during the 20-day period was 0.05 (which will be designated as $\bar{p}$).

2. The formula for control limits on the fraction defective is

$$\bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

(here n is the average daily production)

3. Substituting our values for the end-shield job, we have control limits

$$= 0.05 \pm 3\sqrt{\frac{0.05(0.95)}{1,000}}$$

$$= 0.05 \pm 3(0.0069)$$

$$= 0.071 \text{ and } 0.029$$

Our control limits thus are 0.071 and 0.029, which correspond to 7.1 per cent and 2.9 per cent defective.

As several points fell above and below the limit lines, we know that we should have better results than we are getting. On the days when the fraction defective was 0.089, 0.075, 0.081, and 0.075, there must have been a factor which was not present on other days. If that trouble could be identified and corrected, we could obtain a lower fraction defective.

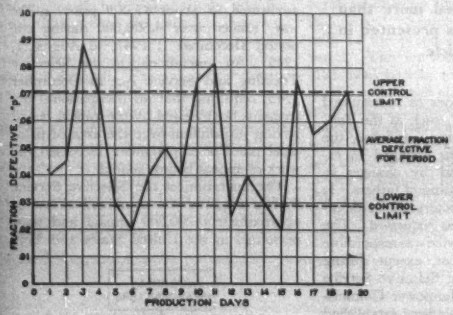

Figure 1. Control chart for fraction defective p constructed from data in Table I

Table I. Data on Inspection of End Shields

Day	Number Units Inspected	Number Defective	Fraction Defective
1	1,005	40	0.040
2	1,000	45	0.045
3	1,015	90	0.089*
4	995	70	0.070
5	1,000	30	0.030
6	985	20	0.020
7	990	40	0.040
8	1,010	50	0.050
9	1,000	40	0.040
10	1,005	75	0.075*
11	990	80	0.081*
12	995	25	0.025
13	1,010	40	0.040
14	1,000	30	0.030
15	1,000	20	0.020
16	1,005	75	0.075*
17	1,005	55	0.055
18	995	60	0.060
19	990	70	0.071
20	1,010	45	0.045
	20,000	1,000	0.050

* Fraction defective above upper control limit.

One of a series of articles prepared in the AIEE subcommittee on educational activities and sponsored by the AIEE subcommittee on statistical methods.

Personnel of the AIEE subcommittee on educational activities: J. Manucle, H. F. Dodge, A. I. Peterson, and R. E. Wareham.

The advantage of using the limit lines was that we could tell definitely how much variation should be allowed instead of judging by opinions and guesswork. If all the points fell within the limit lines, then we would have known that we were getting the best possible results from that process and that further improvement could be made only by changing the design or production methods.

In other words, limit lines offer an index of control. We know that it is practical to hold the fraction defective within these limit lines. Therefore, if the fraction defective is more than the limits allow, we are sure that we can do a better job. On the other hand, if our actual fraction defective is within the limits, we know that we are controlling our operations well and, therefore, we can not expect to get fewer defects unless we change the design of the part or the method of making it. Thus quality-control methods can be of real help in answering the old question, "Are the rejections on this job as low as we can make them?"

When we have made such an analysis and find that the job is out of control, the next step is to segregate the defects by the operations which cause them. Defects in the following operations: machining the rabbet diameter, machining the rabbet face, and boring the bearing hole are known to be the chief causes of trouble with these end shields. Analysis of the fraction defectives from each of these causes will tell us which operation is out of line. (This analysis may be made as outlined in a previous article of this series.[1]) A study of the particular operation will indicate the reason for the high percentage of defectives and point to correction of the trouble.

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Selective Service in World War II

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A brief summary of the organization and accomplishments of the Selective Service System in World War II which registered and classified more than 45,000,000 men is presented in this article.

NO AGENCY of the United States Government has ever affected as many men or the destinies of as many families as the present Selective Service System which came into existence following the passage of the Selective Training and Service Act of 1940. Conceived in peace, it soon became an agency responsible for the rationing of the manpower of a country at war, required on the one hand to furnish to the Armed Forces the number of men necessary for final victory and, on the other hand, to leave in the mines, factories, on the farms and railroads, those men necessary to supply the implements of war, to feed and clothe both the Armed Forces and those at home; all to be accomplished with the least possible disruption of family ties.

ORGANIZATION

The successful operation of this gigantic task undoubtedly has been due to a policy of decentralization. The 6,443 local draft boards in the United States and Territories each were composed of three or more local citizens, working without pay as a patriotic service. On these men fell the real work of classification and selection for military service. A state headquarters for Selective Service supervised the work of the local boards within each state, under the administration of a state director appointed by recommendation of the governor.

The national headquarters of the Selective Service System was concerned primarily with policy and over-all guidance. It revised the regulations as necessitated by revisions in the law, such as the Tydings' Amendment making mandatory the deferment of registrants engaged in essential agriculture, and by changes in policy, such as the drafting of fathers. It dealt with the state directors and made reports to the Congress as requested. The director of Selective Service was responsible directly to the President, except during a period in 1943 when Selective Service was under the War Manpower Commission. Boards of appeal were established in each state with jurisdiction over specified areas. Decisions of these boards on matters of classification were final, except for cases subject to further appeal to the President. (Figure 1 shows organization.)

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PROCESSING OF REGISTRANTS

By August 1, 1945, over 9,600,000 men had been inducted into the Armed Forces through Selective Service. The number sent to the Armed Forces, however, gives only a faint indication of the work performed by local boards, appeal boards, and other agencies of the Selective Service System. This is best illustrated by the fact that over 76,000,000 classification actions have been made in the course of processing and reprocessing registrants of military age. Over 31,000,000 men under 45 years of age were registered and classified by local boards, and an additional 14,200,000 aged 45–65 were registered.

Appeals to state appeal boards, which amounted to about 83,000 prior to the war, totaled over 4,500,000 during the period December 1, 1941, to August 1, 1945. An amendment to the Selective Training and Service Act in December 1943, requiring that all occupational deferments be reviewed by the appeal board having jurisdiction over the area of principal place of employment, increased the work of appeal boards sixfold.

The operation of the Selective Service System required the combined efforts of approximately 200,000 unpaid and paid personnel in the United States and Ter-

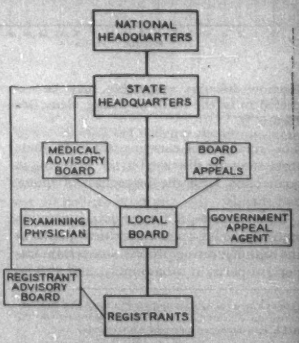


Figure 1. Elements of the Selective Service System

ritories. Included in this number were 24,000 members of the 6,443 local boards, 15,000 re-employment committeemen, 36,000 examining physicians and dentists, 96,000 members of appeal and advisory boards, and 8,000 appeal agents, all working without compensation. The remaining 21,000 were paid full-time or part-time employees.

Some idea of the cost of operating the Selective Service System may be obtained from the financial obligations for the year ending June 30, 1944, which totaled over $65,000,000. The two largest items in this total were $32,000,000 for personal service of local boards (clerks) and $15,000,000 for transportation of selectees.

As data for the planning and operation of the system needed to be furnished on each of 6,443 widely separated local boards and also to each board and state, the greater part of the statistical program was devoted to reporting activities. Problems of accuracy, comparability, flexibility, and promptness resulted in a decision to develop a system of individual punch card records on each registrant, to have these cards available at national headquarters, and to produce such data from them as were required both routinely and specially for the entire system. Data to keep the cards currently correct were obtained from detailed reports forwarded by local boards immediately after each board meeting.

Equal to the reporting work in importance, though not in magnitude, was the analytical part of the statistical program. This phase was concerned with the development of estimates and the accomplishment of research. Examples of the former include the predetermination of the date when it would become necessary to induct fathers (October 1, 1943) and estimated yields for induction from various age groups of the manpower pool. Among the more valuable results of research studies were the Medical Statistics Bulletins and reports on defects of rejected registrants.

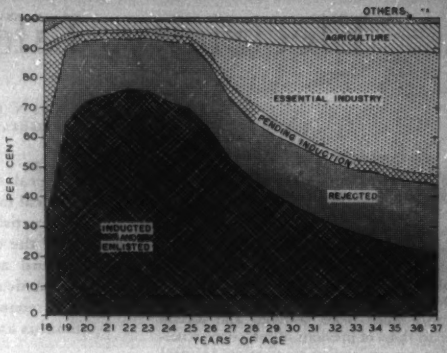
The research reports were obtained largely from sample studies. In this work, four different types were used:

1. A one-per-cent sample of each local board.
2. A sample of each state.
3. A ten-state sample (100 per cent for each of these states).
4. A two-per-cent (125 local boards) sample.

The first type of sample was used to determine the status of registration groups a year after their registration. The sample consisted of every 100th registrant in each local board. Samples of each state were used in the preparation of medical statistics. The ten-state and two-per-cent (125 local boards) samples were used for studies on age and classification. The 125 local boards compose a stratified sample, selected geographically from urban and rural areas, checked as a whole for representativeness with national totals.

One example of the data obtained from the two-per-cent (125 local boards) sample is shown in Figure 2. This clearly indicates the effort on the part of the local boards to induct the younger registrants and defer for essential work those more advanced in age and experience.

Figure 2. Classification of registrants ages 18 through 37 by individual year of age as of March 1, 1945



No attempt was made to accumulate the vast amount of information from the Selective Service questionnaires which were filled out by all registrants of military age. These data were required only by local boards for purposes of classification, hence the expense of compilation could not be assumed by the Selective Service System. This information, if compiled by states, would be of great sociological value.

CONCLUSIONS

The Selective Training and Service Act of 1940, as amended, followed very closely the final form of Selective Service in World War I. Both authorized "selective draft" for the Armed Forces from citizens aged 18–45 for the period of emergency; forbade bounties, substitutes, and purchased exemption; exempted outright only ministers, divinity students, and high public officials; exempted conscientious objectors from combatant service; and authorized exemptions at Presidential discretion for essential occupations and dependency. Both established the state as the unit for quota allotments; authorized local boards and appeal boards.

The United States is fortunate that the Congress passed its first peacetime conscription law in 1940 instead of waiting until that fateful day of December 7, 1941. When the country awoke to find itself engaged in a global war, the Selective Service System was in full operation.

The successful operation of Selective Service in two world wars has been due largely to the fact that the programs were instituted in time, at the beginning or prior to the outbreak of hostilities. The obligation of service was personal and nontransferable, and no group received favoritism. If mistakes were made, they were in full view of the community, as all classification and selection for induction or deferment was made locally by the registrants' neighbors. The armies indeed were raised by the civilians at home.

Use of Electron Microscope in Dust Study

To the versatile electron microscope has been added another function: the determination of the size, distribution, and shape of infinitesimal particles of dust and pollen in the air. A subject of considerable interest to the air-cleaning industries, the study of these particles has been limited by the magnifying power of the light microscope, which can give information on particles above five microns in size only.

But the electron microscope, with its magnification of up to 50,000 diameters, can recognize particles as small as 0.005 micron, and can determine the form of those 0.02 micron or larger. Such studies are being made in the research laboratories, Westinghouse Electric Corporation, East Pittsburgh, Pa., on dust, smoke, and pollen.

Because the electron microscope can penetrate matter to a depth of only 0.01 to 0.05 micron, the specimens must be collected on an extremely thin film of collodion or other plastic material. This in turn is mounted on a 200-mesh stainless-steel screen $^1/_8$ inch in diameter. Tobacco-smoke particles can be collected by holding the film and screen in a trail of smoke for a few seconds. Dust can be gathered by making the specimen the negative and a fine point the positive electrode.

With this microscope not only can the nature of the foreign material in the air be studied, but also the efficiency of the air-cleaning process itself can be evaluated.

Electricity, Life, and Sensation

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With several of the historical physiological investigations as a basis, this article presents a discussion of the electrical characteristics and activity of living matter, particularly of nerves and the connection between stimulus and sensation.

FROM THE STUDY of physical surroundings, the curiosity of some investigators turns inward on men themselves. *What is life? What is man?* These philosophical questions have challenged thinkers of all ages along with questions as to the nature and purpose of the world. Now, equipped with concepts and apparatus much more powerful and precise than those of previous investigators, scientists are attempting to correlate physical measurements with physiological and psychical activity of living organisms, with hunger, emotions, sensation, thought, and so forth.

Because modern electric detecting instruments are very sensitive and because electric stimuli can be controlled accurately, investigations of the electrical characteristics of living tissues have been extensive. These investigations have shown that the maintenance of electric potential differences and a sensitivity to electric stimuli are two universal characteristics of living matter, plant or animal. The potential differences and the sensitivity disappear as life disappears. A potato or a horse will have a potential difference of 10 to 100 millivolts (about a hundredth to a tenth the voltage of a flashlight battery) between the inside and outside of its tissues while living. By so little a potential difference is life evidenced and maintained.

Furthermore, all sensory or motor impulses in nerves are accompanied by volleys of pulses of electric potential variation, pulses of constant magnitude traveling down the nerve at speeds of 10 to 100 miles per hour.

To appreciate the truth-seeking research underlying these generalizations and to understand their significance, let us review briefly some of the historic investigations of the electrical characteristics and activity of living matter, particularly of nerves. See how keen logic and improved apparatus became the tools of man's curiosity in uncovering some laws of his own being and activity.

Let us throw ourselves as much as possible into the confused state of mind of early investigators. Do you believe in "animal magnetism"? Do you believe in "animal electricity"? Magnetism is as respectable a physical phenomenon, in this year of 1786, as is electricity. Why should animal magnetism be any less probable than animal electricity? This is an age of scientific miracles—Benjamin Franklin with his kite drawing electricity out of the skies. Who knows what these men with insatiable curiosity may discover next?

Luigi Galvani, an anatomist and physiologist by profession and professor at the Institute at Bologna, believed in the existence of animal electricity. Perhaps he reasoned something like this. Joseph Duverny back in 1700 noted that the limbs of a frog are convulsed by an electric discharge. And certainly since the development of the Leyden jar in 1745 many a careless experimenter can testify to the fact that his nerves and muscles were stimulated by an electric discharge. If living tissues are sensitive to electricity, must they not partake of the nature of electricity? (Newton, in England, showed that bodies acted on by the force of gravity themselves possess mass, the property of matter from which the gravitational force seems to arise.) Similarly, animals may themselves contain electricity since they are susceptible to its influence.

After experiments on the effects of external electric discharges in producing muscular contractions, Galvani tried to demonstrate the presence of electricity within the muscle itself. In 1786 he hung the freshly skinned legs of a frog by a copper hook through the spinal cord and noted vigorous contraction of the frog's legs when they touched the iron stand to which the copper hook was fastened. Later experiments showed that contractions took place whenever metallic connection was made between spinal cord and leg muscle. To explain the contractions Galvani assumed that the muscle contained animal electricity and acted as a Leyden jar with outer surface negative and inner surface positive. The leg nerve was considered to be the conductor of the Leyden jar; it supplied the muscle with electricity, presumably from the central nervous system. The discharge of the muscular Leyden jar caused contractions of the leg. Galvani's experiments were published in 1791 and aroused great scientific and popular interest. The frogs fared badly.

Alessandro Volta, professor of physics at Pavia, Italy, at first accepted Galvani's results, but in the course of his investigations observed that, except in favorable circumstances, contractions could be produced only by touching the frog with rods of different metals. He then advanced the opinion that the muscular contractions were caused by electricity generated from touching the limb with dissimilar metals. This was the beginning of a long controversy between Galvani and Volta.

Galvani extended his researches to meet Volta's objections, obtaining contractions merely by touching nerve to muscle with no metal present. This experiment might have been convincing had he not attempted to explain away entirely the generation of electricity by contact of dissimilar metals. Volta in his turn piled up experiments to prove the generation of electricity by two heterogeneous metals in a moist conducting medium. His views prevailed, especially when death called Galvani from the field of controversy in 1798 and when Volta developed the voltaic battery in 1799.

In reality Galvani had stumbled upon a complex phenomenon involving both animal electricity and electrolytic generation of electricity, and both he and Volta had overstepped their scientific observations in asserting the existence of a single action. An "either-or" theory was too simple (as it so often is) to explain the observed events. The great German naturalist Alexander Humboldt perceived this, pointed out the limited applicability of Volta's experiments, and published some researches establishing quite con-

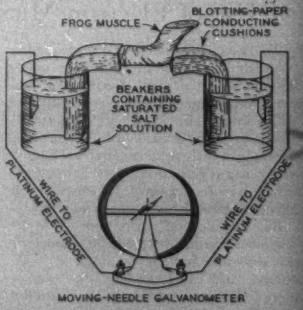

Figure 1. Typical setup for du Bois-Reymond's experiments with animal electricity

Essential substance of an article published in the June 1945 issue of the *Northwestern Engineer*, a student publication of Northwestern University.

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clusively the existence of animal electricity. In spite of this and some writings by Aldini, Galvani's nephew, the existence of animal electricity was discredited and practically disappeared from scientific investigation until 1827.

Investigations into the current electricity generated by the voltaic cell monopolized electrical experiments after 1800, and the concept of an electric circuit became fundamental. Oersted discovered the magnetic effect of current in 1820, and Schweigger developed a moving needle galvanometer two months later. Also in 1820 Ampere discovered the force on a wire carrying current in a magnetic field. Ohm's law was published in 1825, and Faraday's discovery of electromagnetic induction came in 1831. The development of these new concepts and apparatus influenced the study of animal electricity greatly.

The invention of the galvanometer provided the means whereby investigations of animal electricity were once more brought to the fore. In 1827 a French investigator Nobili devised a very sensitive galvanometer and demonstrated the electromagnetic effect of the "frog current" as it came to be known. Nobili placed the spinal cord and feet of a frog in separate vessels containing brine or water. When the circuit between the two vessels was completed through a galvanometer, the frog's muscles contracted and might continue to give a current for several hours. The deflection of the galvanometer needle indicated a positive current passing from muscle to nerve, or feet to head, in a frog.

An Italian, Matteucci, demonstrated that current from the lower to the upper part of a frog leg could be obtained with all nerves removed. This discovery overthrew the Voltaic doctrine of electrolytic action between nerve and muscle and upset Nobili's thermoelectric theory based on differential rates of cooling between nerve and muscle tissues. Matteucci also constructed weak batteries of frog hearts and pigeon thighs. His work laid the basis for the investigations of Emil du Bois-Reymond a great German physiologist (1818–96) who quite properly may be called the father of the science of electrophysiology.

The questions which du Bois-Reymond tried to answer were: what are the laws describing correctly the actions of animal electricity, and what is the origin of animal electricity? The existence of a phenomenon having been demonstrated, the problems of describing its manifestations and finding the causes of its existence were next to be approached.

How could animal currents be measured? By means of a galvanometer. Nobili had noted that frog muscles often contracted when his galvanometer needle showed no deflection. So du Bois-Reymond constructed more sensitive galvanometers.

How were the galvanometer leads to be connected to the frog tissues? The effects of small currents caused by slight dissimilarity of the electrodes must be avoided. Platinum electrodes carefully cleaned and heated to incandescence were attached to the galvanometer leads and dipped in saturated salt solutions in separate vessels. Cushions of blotting paper, each with one end dipping in the salt solution and the other over the edge of one vessel, were used as electrodes to connect to the muscle or nerve being studied. To protect the frog tissues against the corrosive action of the salt solution, the conducting cushions were covered with a guard of pig's bladder moistened with the white of an egg. In a typical experiment the conducting vessels with their platinum plates were connected into a closed circuit through the galvanometer to make sure that no voltaic action was present at the electrodes. Then the conducting cushions were separated and a muscle or nerve placed between them. The experimental setup is illustrated in Figure 1.

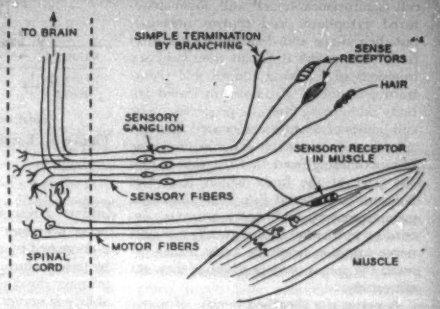

Figure 2. Diagrammatic representation of a nerve and its connections

This circuit arrangement and experimental procedure are described in some detail because the technique developed by du Bois-Reymond became the standard for later investigators, and they illustrate some of the niceties which must be introduced in experiments on animal electricity to avoid erroneous results.

What is the general law of muscular currents? Du Bois-Reymond discovered that if a muscle were cut in two and the cut or transverse section placed on one conducting cushion and the uninjured muscle sheath, or longitudinal section, on the other, a comparatively strong current was set up in the galvanometer. The current was directed from the transverse section (cut surface) of the muscle to the longitudinal section (sheath) *within the muscle*. This direction proved the same for all animals. Du Bois-Reymond in 1843 formulated the law for muscular currents as the antagonism of the transverse and longitudinal sections, the cross section of the muscle acting as the negative and the outside of the muscle as the positive terminal of a battery. The experiments on tissue currents later were refined to show that the same law held for the individual fibers of which the muscle was composed.

Because of the greatly increased sensitivity of his galvanometer over those of previous investigators, du Bois-Reymond was able to detect a small electric current in nerves also, and this current was directed similarly to that in muscles, that is, in such a direction as to indicate that the cut section was negative with respect to the sheath of the nerve.

So much for the "resting currents" of muscles and nerves. What are the conditions under which an electric current could stimulate living tissues? Du Bois-Reymond extended the investigations of previous experimenters, using as stimuli induction shocks and constant currents let into the muscle or nerve by electrodes applied at different points. Either the muscle or its nerve could be excited. When a constant current was used to stimulate the leg nerve, muscular contraction took place at make and break of the circuit but did not continue all the time the current was flowing. This, together with the fact that contractions appeared more vigorous if the current were made to rise or decline more rapidly, led du Bois-Reymond to announce this law of electric excitation:

> **"The motor nerve is not excited by the absolute density of the current, but by the variations of this amount from one instant to another, and the excitation caused by these changes is the greater the more rapidly the changes take place, or the greater they are in any given time."**

He carefully pointed out that this law applies strictly to motor nerves only. Sensory nerves are affected by a steady current. Thus taste nerves give a continuous sensation as current is passed through the tongue and a continuous hum is produced by a constant current flowing into the ear.

Following the basic experiments of du Bois-Reymond, there was a great deal of research into animal electricity during the second half of the 19th century. Let us summarize a few of the outstanding discoveries with regard to the electrical activity of nerves and see what understanding they may give into the nature of sensation.

Nerve cells, called neurons, possess all the structural characteristics of a typical

cell (semipermeable cell wall, foam-structured cytoplasm, and central nucleus), but their shape and detailed organization have been modified to suit their primary functions of receiving stimuli and transmitting impulses. From the nucleated cell body extend long fibers, or processes. The cell bodies of neurons are located near the spinal cord, and each cell has one long fiber extending from that location out to the part of the body which it serves. Neurons are classed into two functional groups, sensory and motor neurons, according to whether they normally transmit nerve impulses from the body tissues toward the spinal cord or whether they act conversely.

A nerve is a sheathed bundle of many individual nerve fibers, both motor and sensory fibers existing in one nerve. (The sciatic or leg nerve of a frog contains over 3,000 fibers.) The fundamental structural features of nerves are illustrated in Figure 2.[1] Specialized developments of the nerve endings give rise to receptor organs particularly sensitive to certain types of stimuli.

Many investigators studied the conditions under which a nerve was excited by electric stimuli. They touched two electrodes to a nerve and sent various types of electric currents between the electrodes; constant currents, single induction pulses, repeated pulses, and so forth. Electric currents have been used as stimuli in nearly all studies of the excitability of nerves, for the currents do not injure the nerve and they can be measured easily, graded in intensity, adjusted in duration, modified in wave form, and repeated exactly and rapidly. Their use in studying the normal behavior of nerves has been justified by the theory that the response of a nerve is the same whatever may be the particular type of stimulus which excites it, a theory which has been well substantiated. For example, a sensation of light may be produced by a light on the retina, by a blow on the head, or by passage of an electric current through the eyeball.

It was discovered that a nerve possesses a definite threshold for a given type of stimulus, such that stimuli weaker than the threshold value fail to excite the nerve. A certain minimal rate of change of stimulus is also necessary, though du Bois-Reymond exceeded the bounds of scientific caution and exactitude when he stated that excitation of motor nerves depended on this factor alone and not on the current density. Duration of a stimulus is another factor; a strong stimulus can give rise to excitation in a shorter time than a weak stimulus. It was discovered also that following initiation of a response in a nerve there is a short insensitive or refractory period, a few thousandths of a second, before a new stimulus will initiate a new response. There is also an inverse phenomenon of summation in which two subthreshold stimuli applied in quick succession may

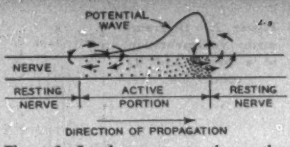

Figure 3. Local currents at active portion of nerve

initiate a response. The sensitivity of a nerve decreases as the excised tissue dies, is decreased by anesthetics, and is affected by temperature variations. These are the primary discoveries regarding the excitability of nerves.

Now what of the second characteristic activity of nerve fibers, the transmission of nervous impulses? Apparently a wave of negative potential variation sweeps down a nerve fiber as an impulse travels along it, for two electrodes placed on a nerve fiber can pick up the potential differences as the impulse travels by. The potential differences may be amplified and recorded accurately by means of various types of galvanometers, electrometers, and oscillographs. The potential waves may be detected whatever type of stimulus is used to excite the nerve; they do not depend on electric stimuli.

Early experiments proved that impulses may be conducted in either direction along either type of nerve fiber. Measurements of the time lag between the initiation of a nerve impulse at one point and its reception at another point indicated the following rates of conduction of nerve impulses: 8 meters per second for nerves of smooth muscles in mammals, 6 to 12 meters per second in the claw nerve of the lobster, 27 meters per second for the motor nerves of a frog at room temperature, and 25 to 200 meters per second in various motor and sensory nerves of man. The low rate compared to the velocity of light upset old ideas that nervous impulses were simply electrical impulses conducted along nerve fibers as cables. It made a chemical form of propagation seem more likely.

Conductivity of nerves is lost at death and is weakened or destroyed by various anesthetics. Rate of conduction rises with temperature. This temperature dependence, quite similar to that of many chemical reactions, suggests once again the probability that chemical alterations are the underlying physical phenomenon.

On the basis of such evidence as that indicated in the foregoing the German physiologist Hermann suggested an electrochemical theory to explain the phenomena of excitability and conduction in living tissues, postulating that electrochemical reactions at the stimulating electrodes gave rise to chemical effects which propagate themselves along tissues. Hering, German physiologist and psychologist at the University of Leipzig, extended the theory by relating the chemical effects to physiological processes of tissue construction and destruction. The commonly accepted theory today, the membrane theory, may be regarded to have developed from the electrochemical theory of Hermann and Hering.

According to the modern theory the cell membranes of living tissues act as a semipermeable "ionic sieve" which maintains a higher concentration of negative ions in their interior than in the surroundings. Thus the inside of the tissues becomes electronegative with respect to the surrounding medium, and a layer of positive ions may collect on the outside of the tissue walls, making a sort of condenser arrangement of the membrane. This is the state of dynamic ionic equilibrium when the cell is at rest; the potential gradient across the cell membranes promotes nutritive chemical reactions which maintain the protoplasm of the cells and keep the cell walls semipermeable.

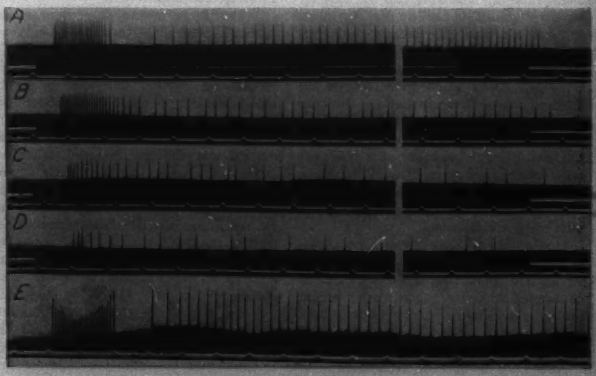

Figure 4. Action potentials of a single nerve fiber in the optic nerve of a horseshoe crab

When the concentration of positive ions outside the cell wall is destroyed, it is thought that the "depolarizing action," if sufficiently great, changes the chemical activity of the protoplasm in such a way that the cell wall becomes unstable, loses its semipermeability, and permits eruption of the negative ions from within the cell. This efflux of negative ions constitutes excitation; it accounts for the negativity which appears in an active region of tissue and for the wave of negative potential variation which is associated with the nerve impulse.

The ion flow does two things:

1. It excites adjacent regions of the tissue.
2. It brings about a state of insensitivity (refractory state) in the active regions.

The action is illustrated by a diagram from R. S. Lillie,[2] professor of physiology at the University of Chicago, which is shown in Figure 3. A wave of negative potential difference is progressing down a nerve to the right. The relative magnitudes of the negative potentials (with respect to resting nerve sheath) are indicated for points in the active region. Local currents flow from the resting nerve to the excited region (or negative ions from active to resting regions). This flow stimulates the nerve on ahead of the excited portion. Of course, local currents circulate behind the negative portion also, but the failure of these to set up excitation may be accounted for as a result of the more gradual potential slope of the latter portion of the negative wave or on the assumption that portions of the nerve which have just undergone stimulation are less than normally excitable. The net result is that the nerve impulse propagates down the nerve to the right by an electrochemical transmission of the excited portion along the nerve.

By means of the improved apparatus for detecting and recording small, quick potential variations, the electric wave accompanying the nerve impulse has been "mapped" accurately during the present century. It is a sharp, short, "spike" type of wave. As a nerve impulse passes under a detecting electrode placed on a single nerve fiber, the potential rises to a maximum of perhaps a millivolt in 0.005 second and then falls nearly to zero in three times that long, though the final decline is very gradual and zero may not be reached for 0.010 second. Pictures of these spike potential waves may be seen in Figure 4. The spike part of the impulse seems to be the characteristic nerve reaction necessary for the transmission of messages. The height of the spike varies with the physiological state of the nerve fiber but not with the type or magnitude of the stimulus which initiated the nerve impulse. Final proof of this fact came in 1926 when E. D. Adrian and Y. Zotterman, physiologists at Trinity College, Cambridge, England, succeeded in recording photographically the potential waves resulting from exciting a single sensory nerve fiber. Appreciation of this fact is vital to an understanding of the action of nerves. The nerve impulse is an activity of the living nerve tissue and not a purely physical effect of the stimulus. The energy of propagation for the impulse is derived from the nerve itself and not from the stimulus. Indeed, the transmission of the nerve impulse often has been compared with the firing of a train of gunpowder, where the energy of transmission is derived locally from the combustion of successive portions of the train.

But this proposition, that nerves exhibit an all-or-none type of response, raises some interesting questions. Hermann back in the 1860's noted that the magnitude of the muscular contraction of a frog leg increased as the strength of the current exciting its nerve was increased, at least until a maximal contraction was reached. Such an effect might be caused, however, by an increasing response in each nerve fiber or by an increase in the number of nerve fibers excited by the stronger currents. That the latter hypothesis is the correct one was demonstrated quite conclusively by Keith Lucas in 1909.

Lucas, a brilliant English investigator and fellow at Trinity College, Cambridge, combined keen insight, manipulative skill, and cautious scientific judgment. His classic and beautifully reported experiment dealt with contraction of the skeletal muscle fiber.[3] It had been shown that the nerve supplying the small cutaneous dorsi

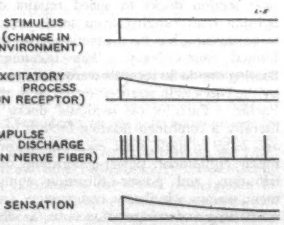

Figure 5. Relation between stimulus, sensory message, and sensation

muscle of the frog contained only nine or ten individual nerve fibers. Lucas reasoned that if this nerve were stimulated by gradually increasing strengths of current, the muscle contractions would substantiate one or the other of the above hypotheses. If the increase in muscular contraction were gradual, an increase of the magnitude of the nervous impulse in each fiber would be indicated. But if the magnitude of contraction increased in discontinuous jumps as the stimulus increased continuously, an all-or-none type of muscle response would be indicated, with the muscular contraction depending solely on the number of active fibers.

Lucas fixed one end of the muscle to a stationary support and attached the other end to a lever bearing a mirror. A light beam reflected from the mirror was photographed and gave a magnified picture of the muscular contraction. The nerve was stimulated by an induction shock whose strength was increased by gradually approaching the secondary to the primary coil. The graphs of magnitude of muscular contraction as a function of distance between the induction coils showed that the muscular contraction rose to its maximum in a number of definite steps which was always less than the number of nerve fibers. Apparently each nerve fiber stimulated certain muscle fibers, and once a given nerve fiber was excited by the stimulus, all the muscle fibers which it served were stimulated to maximal contraction.

Though Lucas carefully pointed out that the all-or-none characteristic of the muscular contraction could not certainly be referred back to the nerve-fiber impulses themselves, his experiment added plausibility to the theory of all-or-none action in the nerve fibers.

However, a further question remains. Graduations of sensation, say of light or of sound intensity, seem to be continuous. Certainly the number of levels of light and sound intensity which can be discriminated exceeds the number of fibers in the optic or auditory nerve. How can this be possible if each nerve fiber, once stimulated, gives a maximum response?

The answer to this question was long foreshadowed, but the final verification of the true hypothesis was thrilling and conclusive. Du Bois-Reymond had noted that sensory nerves gave continued response to a constant current stimulation, instead of separate, short responses at make and break of the current as did muscles and motor nerves. Later investigators discovered that muscles and motor nerves might respond to very strong shocks by a tetanic contraction or by a series of impulses. Apparently a muscle or nerve after responding to a stimulus in its characteristic way becomes incapable of further excitation for a short (refractory) period, and then recovers excitability. A strong or continued stimulus may then initiate a new response. This repeated excitation of a muscle or motor nerve by a strong stimulus does not continue for long, because the tissue apparently adapts quickly to the changed environment of the stimulus and ceases to give further response. But sensory nerves, or their end organs, seem not to adjust quickly to a changed environment so that they send out a continued volley of nerve impulses in response to a continued stimulus. The stronger the stimulus the shorter will be the time interval between successive impulses, for a stronger stimulus can initiate a new impulse earlier in the refractory period as the nerve (or end organ) gradually regains its excitability. Thus stronger stimuli send higher frequency volleys of nerve impulses down a sensory nerve. Information re-

garding the magnitude of sensory stimuli is carried to the brain by frequency modulation of a train of nerve impulses in the sensory fibers.

The experiment of Hartline and Graham on the eye of a horseshoe crab was an exciting and clear demonstration of the correctness of the foregoing hypothesis. These two American physiologists, working under grant from the Johnson Foundation, succeeded in 1932 in obtaining the first records from a single optic nerve fiber. The logic of the experimenters and the wonderfully adequate technique of the investigation leave little to be desired.

The excised eye and optic nerve of the horseshoe crab were placed in a moist chamber with the surface of the eye protruding from a small window. The nerve was slung across two threads soaked in sea water, which served as recording electrodes for the moving reed oscillograph used to record the potential variations from the optic nerve. The variable intensity light which provided the stimuli in the experiment came from an electric lamp through a small diaphragm and was focused on the eye by means of a microscope.

To yield the pulses from a single nerve fiber, the optic nerve was floated in sea water and teased apart with a fine glass needle. The isolated bunches of nerve fibers remaining then were tested and further dissected until the electric response to illumination showed only a single series of impulses. Records obtained in this manner are shown in the photographic strips of Figure 4.[4] The records from *A* to *D* show the electric responses in the optic nerve as the stimulating light intensity was decreased in steps, 0.1, 0.01, 0.001, and 0.0001 arbitrary units respectively. The gaps in the records indicate intervals of several seconds in each case. Record *E* shows the effect of high frequency of response (intense stimulus) on the height of the potential spikes during the initial outburst of activity.

After the initial outburst the height of the individual pulses is constant (about 0.3 millivolt), proving the all-or-none activity of the nerve. Only the frequency of the pulses changes with the intensity of the stimulus. The variation of frequency with intensity of stimulation shows approximately the logarithmic relation predicted by the Weber–Fechner law of sensation. The maximum frequency observed was 130 impulses per second. (In human auditory nerves frequencies up to 1,000 per second have been detected.)

So it is with other sensory nerves. Sensations of sound, touch, pain, and heat apparently are conveyed to the brain as a series of nerve impulses of constant height whose frequency varies with the intensity of the stimulus. The impulses traveling in different types of sensory nerves apparently are similar, so that the brain must distinguish different sensations by identifying the nerve fibers sending in messages rather than from any peculiarity of the message received.

The detailed activity of the brain in interpreting sensory nerve impulses is not known as yet. One estimate of its behavior, however, might be made. The nerve impulses are abrupt, discrete variations, while sensation seems to be a gradual continuous phenomenon. We might guess, then, that the brain acts in some way to integrate the rapid volleys of discharges from the sensory nerves, much as would a galvanometer of long period when rapid pulses are sent through it.

On the basis of this guess our present knowledge of the links between stimulus and sensation might be pictured as shown in Figure 5, taken from E. D. Adrian's "The Basis of Sensation."[1] The sudden, constant change in the environment (stimulus) produces excitation in the sensory end organs, but the excitability decreases more or less gradually as the end organs accommodate to the changed environment. The changing excitability of the end organ is transmitted by the sensory nerve as a series of pulses whose frequency varies with the reaction of the sensory receptor. The brain integrates the pulses from the sensory nerve to obtain a sensation which is a more or less faithful reproduction of the stimulus according to the fidelity of response in all parts of the system involved.

So the study of nerves and sense organs enables us to make a little better guess as to the answer to the question: what is sensation? As Adrian says,

"It does not bridge the gap between stimulus and sensation, but at least it shows that the gap is a little narrower than it was before."

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2. Protoplasmic Action and Nervous Action (book), R. S. Lillie. University of Chicago Press, Chicago, Ill., 1923.

3. The "All-or-None" Contraction of the Amphibian Skeletal Muscle, Keith Lucas. *Journal of Physiology*, volume 38, 1909, page 113.

4. Nerve Impulses From Single Receptors in the Eye, H. K. Hartline, C. H. Graham. *Journal of Cellular and Comparative Physiology*, volume 1, 1932, page 277.

Speeding Repairs on Fighting Craft

Disclosure of how electric equipment, supplied on a rush basis by seven major plants of the General Electric Company, Schenectady, N. Y., operates in the Navy's advance-base section docks to speed repairs on fighting craft ranging from small vessels to battleships, has been sanctioned by the United States Navy. The mammoth floating dry docks recently were announced by the Navy as in strategic locations in the Pacific. Each of the sectional docks is literally a combined floating factory unit and hotel in itself, since each has its own repair equipment, power-generating, distribution, and power-utilization equipment, pumps, windlasses, compressors, and ventilating and refrigerating units, as well as full facilities for accommodating a crew of 40.

An elaborate system of motor-operated valves and powerful pumps driven by 200-horsepower vertical motors submerge and raise these docks, and capstans operated by 30-horsepower motors warp the damaged vessels into them. Remote-operated level indicators in a control house, showing the level of the water in the various ballast chambers, assist the dock master to direct these operations over an intercommunicating system to operators stationed at control panels in each section.

The docks are equipped to supply the vessel under repair with both a-c and d-c service. Alternating current is derived from a bus fed by generators rated 438 kva, two of which with the necessary switchgear and related equipment are located in each section. The d-c service is obtained from a 300-kw 250/125-volt three-wire sealed ignitron rectifier. The power-generating equipment is unique in that it is designed so that when a ten-section dock is used for repairing a battleship, thus requiring all 20 438-kva generators to be operated in parallel, current-limiting reactors are connected to limit short-circuit currents.

In addition to the major electric equipment, each section is equipped with one 1-horsepower and three 5-horsepower fresh-water pump motors with full voltage starters; one $7\frac{1}{2}$-horsepower salt-water circulating pump motor; one 3-horsepower ventilating-fan motor; and a number of other motors of various sizes for refrigerating, compressor, anchor windlass, sewage disposal, and fire-fighting purposes. Each dock also has two electrically driven revolving jib cranes, both of which are protected by crane-stability gauges.

Other than being selected with the view to meeting the rigorous conditions imposed by dry-dock service, much of the electric equipment is, but for minor modifications, of standard design. The metal enclosed switchgear for controlling the generators, however, was custom-made for the application, with the power output connected to a specially designed distributing system. Also, the 10-, 25-, and 50-kva transformers for ship service, lighting, and heating circuits, respectively, as well as the 300-kw rectifiers for supplying d-c service, were required to be designed to withstand mechanically the 90-degree tilting of the wing walls of the docks. This tilting takes place when the wing walls are folded flat to the decks of the sections to facilitate towing the docks from one location to another.

INSTITUTE ACTIVITIES

New Frontiers of the Profession to Be Explored at the Winter Convention

The AIEE winter convention will be held at headquarters in the Engineering Societies Building, 33 West 39th Street, New York, N. Y., January 21–25, 1945. Both the winter-convention committee and the technical-program committee have met and the ground work has been laid to restore the convention with its prewar features, insofar as possible, including the dinner–dance, smoker, and inspection trips. The advantages of these social features with opportunities to renew old acquaintances and good fellowship long have been recognized. The technical program will be almost as broad as the whole range of Institute technical-committee activities.

TECHNICAL PROGRAM

Technical sessions and conferences will provide a series of papers with an approach to the new frontiers of the profession. Many papers will be based on wartime developments which heretofore have been restricted. A conference on education will explore the borderline relationships between physicists and engineers, which may lead to suggestions for changes in curricula. Plans are in prospect by the committee on basic sciences for a possible conference on atomic energy. One of the proposed technical sessions will deal with radar tubes and circuits, provided restrictions are lifted sufficiently to make such a session worth while. Many other papers will treat electronic applications, particularly in the fields of power, industry, and communication. Detailed arrangements are proceeding along the foregoing lines, which altogether promise an interesting, timely, and valuable technical program.

HOTEL ACCOMMODATIONS

The hotel situation in the metropolitan area is acute and quite likely will remain so for some time. Members, therefore, are urged to make their plans early and arrange for accommodations directly with the hotel preferred. The Institute has no connections with any of the hotels and cannot undertake to make reservations.

Members Urged to Place "Supplement" Orders Early

Members desiring the December 1945 *Supplement to Electrical Engineering—Transactions Section* are urged to place their orders before December 15, 1945, to insure obtaining their copies upon publication. Members with standing orders, however, need make no further reservation; upon notification to Institute headquarters, a standing order may be arranged at any time.

This supplement to *Electrical Engineering* will contain technical papers and discussions not published in the monthly issues. Its price is 50 cents to members and it may be ordered from the AIEE Order Department, 33 West 39th Street, New York 18, N. Y. Further details of the supplement's contents and availability will be announced in this section in a subsequent issue.

AIEE Organizes New Planning Subcommittees

Two new subcommittees of the AIEE committee on planning and co-ordination have been appointed to study problems of growing urgency both in the Institute's relations with the engineering profession and with the more highly specialized organization and trends within its own general field. These subcommittees, known as the technical-activities subcommittee and the professional-activities subcommittee, will carry the major burden of fact finding, weighing of evidence, and preparation of recommendations, and thus will render an important service not only to members of the Institute but also to the engineering profession and to society.

The duties of the subcommittees will include a review of the organization, methods of operation, and scope of the technical activities of the Institute and of other engineering and scientific societies. On this basis the technical-activities subcommittee may recommend changes that "the advancement of the theory and practice of electrical engineering and of the allied arts and sciences" may be pursued more effectively and the professional-activities subcommittee may prepare recommendations for changes in organization and improvements in method for the "maintenance of a high professional standing among its (the Institute's) members" and among members of the engineering profession as a whole.

These objectives are to be accomplished by a maximum of co-operation and a minimum of duplication of effort as between the Institute and other organizations and by affording an opportunity for active participation by more individuals. The subcommittees also will recommend changes necessary to render the structure and procedures of the Institute sufficiently flexible and adaptable to take account of progress in the art and the development of new fields of interest and to respond promptly to changing social, political, economic, or other conditions affecting the welfare of society and of engineers.

All members of the Institute are invited to offer constructive suggestions or to express their opinions as to what is lacking in the way of services which should be available to members. Communications may be addressed to Institute headquarters, to

M. D. Hooven, chairman
AIEE Technical-Activities Subcommittee
Public Service Electric and Gas Company
80 Park Place
Newark 1, N. J.

or to

T. B. LeClair, chairman
AIEE Professional-Activities Subcommittee
Commonwealth Edison Company
72 West Adams Street
Chicago 90, Ill.

Additional Officers and Committees Announced

In order to facilitate the work of the AIEE protective-devices committee, the following subcommittees, with attendant personnel, have been formed for 1945–46:

Circuit Breakers and Assembled Switchgear

H. J. Lingal, *chairman*
A. E. Anderson
H. W. Collins
William Deans
H. W. Haberl
J. R. North
H. V. Nye
M. S. Oldacre

Switches, Fuses, and Insulators

H. H. Rudd, *chairman*
H. D. Braley
O. E. Charlton
F. R. Ford
A. H. Powell
H. L. Rawlins
G. V. Smith
J. C. Woods

Lightning Protective Devices

W. J. Rudge, *chairman*
E. W. Beck
F. M. Defandorf
T. H. Mawson
W. E. Rushlow
A. H. Schirmer
H. R. Stewart
E. R. Whitehead

Fault-Current Limiting Devices

F. R. Longley, *chairman*
J. E. Clem
G. B. Dodds
H. P. St. Clair
R. D. Evans
E. T. B. Gross
P. A. Jeanen

Relays

W. A. Lewis, *chairman*
J. C. Bowman
W. R. Brownlee
G. B. Dodds
E. L. Harder
L. F. Kennedy
E. W. Knapp
S. C. Leyland
W. E. Marter
E. L. Michelsen
J. H. Oliver
C. E. Parks
H. R. Paxson
F. C. Poage
J. H. Vivian
C. A. Woods

The following additional appointments to the AIEE board of examiners also have been announced:

R. W. Atkinson
Robin Beach
C. R. Beardsley
C. M. Gilt
J. J. Pilliod
H. H. Weber

A complete list of the officers and committees for 1945–46 appears in *Electrical Engineering*, September 1945, pages 339–43.

Members of Standards Committee Appointed

Supplementing the list of AIEE officers and committees for 1945–46 which was published previously (*EE, Sept '45, p 339–43*) the following names are added as members of the Standards committee. These appointees for the administrative year beginning August 1, 1945, are the following:

R. L. Jones, *vice-chairman*
R. C. Bergvall
J. E. Clem
C. M. Gilt
R. T. Henry
T. B. Holliday
Alexander Maxwell
A. C. Monteith
S. H. Mortensen
J. R. North
M. S. Oldacre
E. B. Paxton
F. B. Silsbee
G. Thompson

Future AIEE Meetings

Winter Convention
New York, N. Y., January 21–25, 1946

South West District Meeting
San Antonio, Tex., April 16–18, 1946

North Eastern District Meeting
Buffalo, N. Y., April 24–25, 1946

Southern District Meeting
May 13–16, 1946.

Summer Convention
Detroit, Mich., June 24–28, 1946

Pacific Coast Convention
Seattle, Wash., August 26–30, 1946

DISTRICT • • • • • •

North West District Executive Committee Meets

The 1945–46 meeting of the North West District (9) executive committee was held in Spokane, Wash., September 28, 1945. G. K. Haspel (M '31) dial telephone engineer, plant department, British Columbia Telephone Company, Vancouver, British Columbia, Canada, was present to attend the discussion on Section operation and management.

A. V. Eastman (M '40), E. W. Schilling (A '29, F '44), and W. E. Enns (A '37, M '44) were appointed judges for the District prize-paper competition. J. F. Gogins (A '40) was selected to represent the North West District on the nominating committee.

The meeting concluded with a four-hour conference on Section operation and management.

The Seattle Section will continue with its plan for holding the Pacific Coast convention in Seattle in August 1946.

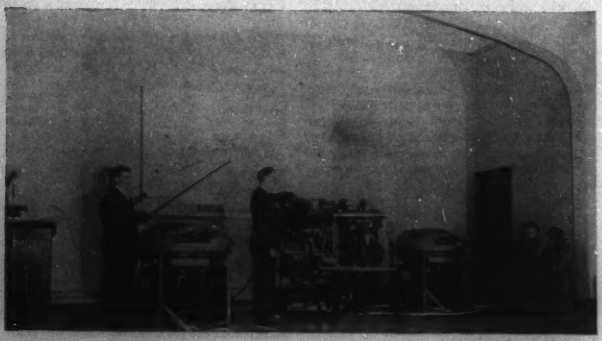
District Conferences on Section Operation

Since the usual delegates meetings were not held during the current year because of the cancellation of the summer technical meeting due to the war emergency, District conferences on Section operation and management have been developed by the Sections committee. These are to serve as a substitute program for the benefit of the incoming Section officers, and to help maintain the high level of interest of all Section officers in Section operation and management.

The conferences are being conducted by the District vice-presidents, and arrangements have been made for the Sections committee representative located in each District to attend his respective conference, and materially aid with the discussions. In several Districts, a plan is under way for the host city to hold a meeting of the Section on the evening of the District meeting so that the Section representatives attending the conference will have a further opportunity to increase the number of personal contacts among the members of the Section in that city.

No conference is to be held in New York City District (3), as this District comprises only one Section. At the request of Canada District (10), arrangements were made for the District officers and officers of the Montreal and Toronto Sections to attend District (1) meeting and for the Section officers of the Vancouver Section to attend North West District (9)meeting.

The first of these series of meetings was held in North Eastern District (1) at Schenectady, N. Y., June 13, 1945, with Vice-President R. T. Henry (A '24, F '33) presiding.



Turrets each mounting a pair of 50-caliber machine guns were used in a first public demonstration on the Pacific coast of the B-29 remote-control turret system at the June 19, 1945, meeting of the AIEE Seattle Section. The system permits gunners to pass control of the turrets from one to another, and to train the fire of several turrets on a single target. The equipment, shown from left to right, is the upper rear turret, power units and computer (in the background), ring sighting station, upper forward turret (with two guns installed instead of four), and nose sighting station. The men from left to right: Lloyd Shackelford, (A '42) service engineer General Electric Company, who demonstrated the system; F. T. Parker (A '42) service engineering department, General Electric Company, and Harry Stavert, Boeing Aircraft Company.

SECTION • • • • •

Subsection in Lake Charles, La.

After considerable preliminary work the executive committee of the AIEE New Orleans, La., Section authorized the formation of a Subsection in the Lake Charles area which formally came into existence March 16, 1945. The area allotted to this Subsection includes the parishes of Beauregard, Allen, Calcasieu, Jefferson Davis, Acadia, Lafayette, St. Martin, Cameron, Vermillion, Iberia, and St. Mary.

Financial assistance, to aid in organizing, has been extended Lake Charles by the New Orleans Section and plans are being formulated whereby operating revenues will be allotted proportionally to the new Subsection. B. H. Bell (A '22, M '43) chairman, New Orleans Section, has extended an invitation to all members of the Subsection to attend functions of the Section whenever possible.

Officers elected are as follows: A. D. Hargroder (A '43) chairman; G. V. Cooper (A '43) secretary treasurer; B. A. Fleshman (M '44) meetings and program chairman; F. I. Stalnecker (A '39) membership chairman; A. E. LeDoux (A '39) publicity chairman; and A. L. Albright, entertainment and attendance chairman.

Two meetings have been held by the new Subsection which have aroused considerable interest in the area. The Lake Charles area is growing fast industrially and it is expected that it will become very strong in itself and may even become a Section. The Subsection is now making plans for future activities and is soliciting additional members and local members.

North Carolina Section Forms Charlotte Subsection

A Subsection of the North Carolina Section, AIEE was formed at Charlotte, October 5, 1945, following authorization by the executive committee of the section at a meeting in Raleigh, August 16. G. O. Bason (A '37) was elected chairman and E. R. Davis (A '41), secretary-treasurer. The subsection was formed in order to afford electrical engineers in the Charlotte area a chance to get together for discussion of advances in the engineering field and of mutual problems.

It is reported that this new activity of the North Carolina Section has made an excellent start. It offers additional opportunities for members to carry out the aims and purposes of the Institute. Institute members living in the Charlotte area are automatically members of the Charlotte Subsection. Plans for the program of meetings of the Subsection are being prepared.

PERSONAL

Edward L. Moreland (A '11, M '15, F '21) partner, Jackson and Moreland, engineers, Boston, Mass., has been appointed 1945–46 chairman of the AIEE ordnance advisory committee. Mr. Moreland was born in Lexington, Va., July 1, 1885, and was graduated from Johns Hopkins University (mathematics and physics) with a bachelor-of-arts degree in 1905. In 1908 he received a master's degree from the electrical-engineering department, Massachusetts Institute of Technology. In that same year, he entered the employ of D. C. and William B. Jackson, consulting engineers, Chicago, Ill., and Boston, serving as personal assistant to D. C. Jackson (HM '44), senior member of the firm. In 1912 Mr. Moreland was made manager of the Boston office and four years later became a partner in the company. During World War I he was captain and later major of engineers, American Expeditionary Forces, serving with the technical board, and as technical executive of the War Damage Board. In 1919 he formed a partnership with D. C. Jackson for the practice of engineering under the firm name of Jackson and Moreland. In 1935 Mr. Moreland was made head of the department of electrical engineering, Massachusetts Institute of Technology, Cambridge, and in 1938 he was appointed dean. Mr. Moreland is the author of several technical papers and has been active in Institute affairs. He has served on many committees including the following: electric machinery, 1929–31; power generation, 1929–31; transportation, 1931–37 (chairman,1931–34); technical program, 1931–34; Standards, 1932–42 (chairman, 1934–36); Institute policy, 1933–34; education, 1936–42; transfers, 1938–41; Lamme Medal, 1940–41; and research, 1940–43.

Lee Francis Adams (A '09, M '26, F '42) assistant to the vice-president and manager, standards division, General Electric Company, Schenectady, N. Y., has been appointed 1945–46 chairman of the AIEE committee on safety. He was born in Bellefonte, Pa., and was graduated from Pennsylvania State College with a bachelor-of-science degree in electrical engineering, subsequently receiving an electrical-engineering degree from the same university in 1909. From 1906 until 1907 he was in the testing department, General Electric Company, Schenectady. For the next two years Mr. Adams was an instructor in electrical engineering at Pennsylvania State College, State College. Since 1909 he has occupied various engineering positions, such as designing engineer, application engineer, and commercial engineer in the General Electric Company. Mr. Adams is an executive representative of the General Electric Company in the National Electrical Manufacturers Association, and represents the National Electrical Manufacturers Association on the standards council of the American Standards Association, and on many engineering committees. He is vice-president of the United States National Committee of the International Electrotechnical Commission, and represented the United States at the International Conferences of the commission in 1926 in New York, in 1935 in Scheveningen, Holland, and Brussells, Belgium, and in 1938 in London and Torquay, England. In 1930 Mr. Adams was awarded the James H. McGraw award for his contribution to the manufacturing branch of the electrical industry. Mr. Adams is also a member of the American Society of Testing Materials, Society of Automotive Engineers, and the National Safety Council. He has written a number of papers on application engineering, Standards, and codes.

Leonard Tibbetts Blaisdell (A '20, M '22, F '39), commercial vice-president, General Electric Company, Cleveland, Ohio, has been appointed 1945–46 chairman of the AIEE committee on transfers. Born in Carlisle, Mass., he was graduated in 1904 in marine engineering from the Commonwealth of Massachusetts Nautical Training School. In 1942 he was awarded the honorary professional degree of electrical engineer from the Case School of Applied Science. He has been continuously employed by the General Electric Company since 1904 when he entered the students' testing course for engineering graduates at Lynn, Mass. From 1907 to 1911 he was in application engineering, and supervisor of power-plant installations on land, also on ships of the Merchant Marine and of the United States Navy. For the next six years he was engaged in commercial engineering, Baltimore, Md. In connection with the General Electric Company's activities during World War I Mr. Blaisdell was transferred to the Washington, D. C., office where he remained as manager until 1923. In the latter-mentioned year he was transferred to Dallas, Tex., as district manager in charge of engineering apparatus lines for the several southwestern states. He was elected a commercial vice-president in 1936. In 1939 he was transferred to Cleveland as commercial vice-president in charge of the company's activities on the engineering apparatus lines for the several states of the east central district. Since March of this year he has been on the president's staff of the General Electric Company. Mr. Blaisdell was vice-president, AIEE, 1936 and 1937, representing the South West District (number 7), and has served as chairman, Washington Section, 1923; chairman, Dallas Section, 1929. He is a member of the Cleveland Engineering Society and of the Illuminating Engineering Society.

Truman S. Gray (A'26, M'38, F'45) associate professor of engineering electronics, electrical-engineering department, Massachusetts Institute of Technology, Cambridge, has been appointed 1945–46 chairman of the AIEE committee on instruments and measurements of which he has been a member since 1935. He was born in Spencer, Ind., May 3, 1906, and received the degrees of bachelor of science in electrical engineering (1926) and bachelor of arts (1927) from the University of Texas, and the degrees of master of science (1929) and doctor of science in electrical engineering (1930) from Massachusetts Institute of Technology. He was named assistant in physics at the University of Texas, Austin, in 1924 and remained in that capacity until 1927 when he became research assistant in electrical engineering at the Massachusetts Institute of Technology. In 1930 he was made instructor in electrical engineering at the institute. He became assistant professor in 1935 and associate professor in 1942. Mr. Gray for short periods was with the Leeds and Northrup Company, at General Electric Company, Schenectady, N. Y., and Naval Ordnance Laboratory, Washington, D. C. Recently he has been consultant to the Climatic Research Laboratory, Quartermaster Corps, Army Service Forces, Lawrence, Mass. His AIEE activities include membership on the committee on instruments and measurements 1933–45 (secretary 1939–41, vice chairman 1941–44); and on the joint subcommittee on electronics (now the committee on electronics), 1934–45. In addition he has served on the executive committee of the Boston Section since 1942, and is vice-chairman of the Section for 1945–46. He is the author of several technical papers and a member of the Society for the Promotion of Engineering Education.

E. L. Moreland

L. F. Adams

L. T. Blaisdell

T. S. Gray

James J. Pilliod (M '17, F '34) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., has been appointed 1945–46 chairman of the AIEE committee on communication. Mr. Pilliod was born in Chillicothe, Mo., and received the degree of electrical engineer in 1908, and the honorary degree of doctor of engineering in 1939 from Ohio Northern University. In 1908 he became associated with the American Telephone and Telegraph Company and filled various positions in Maumee, Ohio, Chicago, Ill., Indianapolis, Ind., and New York until in 1914 he was named division plant engineer, long-lines department, Chicago. Three years later he was in New York as engineer of transmission, long-lines department, and was in charge of a group handling transmission-engineering work involved in the construction and operation of long-distance telephone lines. In 1920 he was appointed engineer in charge of the long-lines engineering department in New York. Mr. Pilliod was made general manager of the long-lines department in 1941 and two years later was appointed assistant chief engineer of the company. From October 1942 to April 1943 he was loaned to the War Department. Mr. Pilliod has contributed many papers to the technical press on long-distance telephony and telegraphy. He has been active in AIEE affairs and has served on the following committees: membership, 1924–25; communication, 1933–37; board of examiners postwar planning (special committee), 1943–45; electrical standards, February 1945–August 1946; alternate, standards council, American Standards Association, February–December 1945, and award of Institute prizes, 1945–46; board of examiners 1945–46, and the 1946 winter convention.

Samuel Galloway Hibben (A '34, M '45) director of applied lighting, lamp division, Westinghouse Electric Corporation, Bloomfield, N. J., has been appointed 1945–46 chairman of the AIEE committee on Production and application of light, of which he has been a member continuously since 1938 with the exception of 1941. Mr. Hibben was born in Hillsboro, Ohio, in 1888, and was graduated from the Case School of Applied Science in 1910. He then joined the MacBeth Glass Company, Pittsburgh, Pa., as illuminating engineer. In 1915 he established an office in Pittsburgh where he worked as consulting engineer. Mr. Hibben's career with the Westinghouse organization began in 1916 but it was cut short a year later when he offered his services to the United States Army. Late in 1917 Mr. Hibben went first to England and then to France with an army searchlight battalion. He rejoined the Westinghouse Company in 1919 and was appointed branch manager at the Cleveland office of the lamp division. A year later he was called to Bloomfield to develop a lighting service bureau which was to become the present commercial engineering department. He was named to his present position in 1933. He is a past national secretary and present director of the Illuminating Engineering Society. He is active in the Society of American Military Engineers, the Electrical Association of New York, and the London Illuminating Engineering Society.

Eivind Urdahl Lassen (A '25, M '33) assistant chief engineer, Cutler-Hammer, Inc., Milwaukee, Wis., has been appointed 1945–46 chairman of the recently formed AIEE committee on industrial control devices. Mr. Lassen was born in Glemmen, Norway, September 30, 1900, and was graduated from the Federal Polytechnical Institute, Zurich, Switzerland, in 1923 with the degree of electrical engineer. His first position upon arrival in the United States in 1924 was as draftsman for Cutler-Hammer, Inc. Later in that same year he was transferred to the engineering department and in 1930 was named to the position of supervising engineer in responsible charge of engineering activities of certain groups and divisions of the company's technical staff. In September of this year Mr. Lassen was appointed assistant chief engineer. Mr. Lassen was secretary-treasurer of the AIEE Milwaukee Section for 1931–32. In addition to his AIEE activities, Mr. Lassen is serving on various technical committees sponsored by the National Electrical Manufacturers' Association, and was active during World War II in committee work sponsored by the Navy Department in the program to bring Navy general specifications for electric control equipment up to date. He is a member of the Engineer's Society of Milwaukee.

S. S. Bloom (M '43) formerly senior engineer, gas and electric division, California Railroad Commission, San Francisco, has become consulting engineer on public-utility questions for Charles C. Bowen and Company, management consultants, San Francisco. Mr. Bloom is a graduate of the University of Idaho.

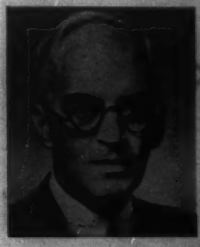
John Castlereagh Parker (A '04, M '09, F '12) vice-president, Consolidated Edison Company of New York (N. Y.), Inc., and past president of the AIEE has been appointed 1945–46 chairman of the AIEE committee on the Lamme Medal. Doctor Parker was born in Detroit, Mich., April 15, 1879, and received the degrees of bachelor of science in mechanical engineering, master of arts, and electrical engineer in 1901, 1902, and 1904, respectively, from the University of Michigan. In 1935 he was awarded the honorary degree of doctor of engineering by the Stevens Institute of Technology. Doctor Parker entered the testing department of the General Electric Company, Schenectady, N. Y., in 1902 and later became an instructor in mechanical and electrical engineering at Union College, Schenectady. In 1904, and for a decade thereafter, he served the Ontario Power Company at Niagara Falls and as assistant to the chief engineer of the construction company building the lines of the Niagara, Lockport and Ontario Power Company. Later he was transferred from Buffalo to Rochester, N. Y., and placed in charge of the engineering department of the Rochester Railway and Light Company. Doctor Parker re-entered the educational field when, in 1915, he was appointed head of the department of electrical engineering, University of Michigan, Ann Arbor, and continued there for seven years. In 1922 he became associated with the Brooklyn (N. Y.) Edison Company as electrical engineer. In turn he was vice-president in charge of engineering and president of the company, and in 1936 when the company became a part of the Consolidated Edison of New York Doctor Parker was appointed vice-president of the latter organization. Doctor Parker, president of AIEE 1938–39, has been active in AIEE affairs. His committees include: Student Branches, 1919–20; educational, 1919–22 (chairman, 1919–20); Sections, 1920–22; Standards, 1923–32; electric machinery, 1924–27; power generation, 1924–26; power transmission and distribution, 1924–26; Lamme Medal, 1931–34 and 1944–47; Edison Medal, 1938–41; executive, 1938–39 (chairman, 1938–39) and 1940–41; and the Hoover Medal board of award, 1941–49.

L. J. N. Mothersill (A '35) lieutenant, Royal Canadian Navy Volunteer Reserve, has rejoined the Brown Instrument Company, Toronto, Ontario, Canada. Lieutenant Mothersill has had five years' service with the Admiralty and the Canadian Navy.

J. J. Pilliod

E. U. Lassen

S. G. Hibben



J. C. Parker

R. A. Millikan (M '22, HM '33) formerly chairman, executive council, California Institute of Technology, Pasadena, has retired. Doctor Millikan was born at Morrison, Ill., in 1868, and received the degree of bachelor of arts from Oberlin College in 1891, and, in 1895 the degree of doctor of philosophy from Columbia University. He tutored in physics at Oberlin (Ohio) College, and in 1896 became an assistant in physics at the University of Chicago (Ill.). In 1921 Doctor Millikan became director, Norman Bridge Laboratory of Physics, and chairman of the executive council, California Institute of Technology. He was the Edison Medalist of 1922, and in 1923 was awarded the Nobel prize for physics by the Royal Swedish Academy. He has contributed liberally to technical literature in his numerous books including "A Course of College Experiments in Physics," 1906; "Electricity, Sound and Light," 1908 and "Practical Physics," 1920. Many articles written by Doctor Millikan have been published in various technical journals. He served on the AIEE Edison Medal committee, 1923–28, 1934–40, and on the electrophysics committee, 1923–30. He was awarded the 1937 Franklin Medal of the Franklin Institute, "for his isolation and measurement of the fundamental unit of electricity, the electron."

H. P. Richmond (A '36) formerly general superintendent, Jersey Central Power and Light Company, Asbury Park, N. J., recently resigned. In 1931 Mr. Richmond was a cadet engineer, Eastern New Jersey Power Company where he gained practical experience in the powerhouse, line department, meter, and test departments. Later he became assistant to the gas engineer of the Jersey Central Power and Light Company, which absorbed the Eastern New Jersey Power Company, and in 1936 he was named district manager of the company at Dover.

C. A. Mullen (A '20, M '20) superintendent, northern division, has been appointed general superintendent of operations, Asbury Park. Since 1909 Mr. Mullen has been identified with a number of companies including the Northern Indiana Gas and Electric Company, Hammond; Brown Manufacturing Company, Zanesville, Ohio; American Rolling Mill Company, Zanesville; and the Penn Central Light and Power Company, Altoona, Pa. In 1914 he was in charge of the testing department of the Ohio Service Company, Coshocton, nine years later was appointed superintendent of substations. Subsequently he transferred to the Pennsylvania Power and Light Company whence he moved in 1927 to Asbury Park where for four years he was superintendent of operations of the former Eastern New Jersey Power Company. Upon purchase of that company by Jersey Central Power and Light Company in 1931 Mr. Mullen was named superintendent of the Morristown division, a position he held until his recent promotion.

H. R. Summerhayes (A '07, F '39) consulting engineer, central-station engineering division, General Electric Company, Schenectady, N. Y., since 1939, retired recently after 49 years of service with that company. Mr. Summerhayes was born in 1875 at Camp Apache, Ariz., and was graduated from Stevens Institute of Technology in 1896 as mechanical engineer. In that same year he joined the expert course in the testing department, General Electric Company. In the foreign engineering department of the company from 1897 to 1911 he had charge of all engineering recommendations on central-station and power and mining projects in foreign countries. He was transferred in 1911 to work in the lighting department, subsequently becoming assistant engineer in that department. Nine years later the lighting department became the central-station department, and Mr. Summerhayes was made engineer. From 1920 to 1939 he had general direction of all the application engineering in the central-station field. He was sent to Europe in 1924 to attend the World Power Conference in London, and to observe central-station practices in various countries. Again in 1935 he went to Europe as a United States representative to attend the meetings of the International Electrotechnical Commission in Holland and Belgium, and the meetings of the International Conference on Large High-Tension Systems in Paris. He was coauthor of a paper entitled "Voltage Standardization of A-C Systems," which aided in establishing a standard for the industry. Mr. Summerhayes has served on the protective devices and Standards committees of the AIEE, and on committees of the National Electric Light Association and the National Electrical Manufacturers Association.

J. L. Gray (M '38) formerly construction engineer, engineering department, East Tennessee Light and Power Company, Bristol, has been appointed manager of power for the city of Bristol in a reorganization resulting from the dissolution of the system operation of the company and transfer of the various units to local municipal government, co-operatives, and the Tennessee Valley Authority. Mr. Gray was graduated with a bachelor-of-science degree in electrical and mechanical engineering from Clemson College in 1919. Directly, he went with Henry L. Doherty and Company on the Toledo (Ohio) Railway and Light Company as junior engineer. Subsequently, he served Durham (N. C.) Public Service Company; Ohio Public Service Company both in Cleveland and in Alliance, and Citizens Light and Power Company, Adrian, Mich. Mr. Gray is a member of the Engineering Society of Detroit.

Abe Tilles (A '30, M '36) electrical engineer, War Research Project, University of California, Berkeley, has joined the staff of the Pacific Gas and Electric Company, San Francisco, Calif. He was graduated from the University of California in 1928 and in that year entered the testing laboratories of the City of Los Angeles (Calif.) Bureau of Power and Light. In 1930 Mr. Tilles became a teaching associate for the University of California and subsequently was made an instructor. He did electrical planning and design for the Los Angeles Bureau of Power and Light in 1936 and in the same year was appointed student counselor for the University of California Branch of the AIEE.

A. C. Monteith (A '25, M '40) manager, industry engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., since 1941 has been appointed assistant manager, headquarters engineering, and director of education. In the former capacity he will direct headquarters-engineering activities in the absence of AIEE Past President C. A. Powel (M '20, F '41) assigned to the military government of Germany. Mr. Monteith was born in Brucefield, Ontario, Canada, and received the degree of bachelor of science from Queens University in 1923. He joined the Westinghouse Company in 1924. He was 1944–45 chairman of the AIEE Standards committee of which he had been a member since 1941. He received honorable mention for the best paper in engineering practice in the 1937 AIEE prize awards, and has served on the power generation committee, 1938–44; protective devices, 1940–42; and Standards, 1941–44.

J. K. Thompson (A '37, M '44) formerly manufacturing engineer, headquarters manufacturing-engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed chief engineer in charge of the transformer and fluorescent instant-start departments, United Appliance Company, Rochester and Geneseo, N. Y. Mr. Thompson was born in Garrettsville, Ohio, and was graduated from Case School of Applied Science with the degree of bachelor of science in electrical engineering in 1931. Before his graduation he was employed for short periods by the Western Electric Company, New York, N. Y., Cleveland (Ohio) Transformer Company, and the National Carbon Company. Following his graduation he served for one year as laboratory assistant with the Brush Laboratories Company, Cleveland, and for ten years as chief engineer, France Manufacturing Company, Cleveland.

W. A. Kelley (A '38) lieutenant colonel, Signal Corps, Army of the United States, has been appointed commanding officer, Lexington (Ky.) Signal Depot. Colonel Kelley entered military service in 1942 and was assigned to the Office of the Chief Signal Officer. Previously he had been with E. D. Smith and Sons, Pittsfield, Mass., and the War Production Board, Washington, D. C. He is the author of "The Universal Catalog System" which is used by the United States Army Air Forces, the British Army Staff, the British War Office, and the Navy Catalog Office.

H. C. Madsen (A '42) manager, university relations, educational department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed manager, industrial relations, Bryant Electric Company, Bridgeport, Conn., a subsidiary of the former company. Mr. Madsen was born in 1913 in Pittsburgh, and was graduated from Pennsylvania State College in 1935 with a bachelor-of-science degree in electrical engineering. Following employment by the Philco Radio and Television Corporation, Philadelphia, Pa., he became associated with the Westinghouse Company.

William H. Reed (A '26, M '43) electrical engineer and consultant, Bruce Electric Company, New York, N. Y., has been appointed the 1945–46 chairman of the AIEE committee on marine transportation of which he has been vice-chairman since 1943 and a member since 1926. Mr. Reed was born in Norwalk, Conn., March 13, 1880, and was educated in public and private preparatory schools there. From 1898 to 1918 he was engaged in design, construction, and operation of central power plants and industrial power and lighting installation, throughout the eastern United States. In 1918 he was named electrical engineer, Tietjen and Lang Dry Dock Company, Hoboken, N. J. (later known as the Todd Shipyards Corporation), in charge of design and supervision of electric power, lighting, and communication installations on ships under repair and conversion in that plant. He was also in charge of the company's generating plant and substations, and of design and supervision involving change of motive power from steam engines to electric motors. He severed his connection with that corporation in March 1945. Mr. Reed is a member of the Society of Naval Architects and Marine Engineers.

H. C. Wolf (A '16, M '23) president of the Atlanta (Ga.) Gas Light Company, has been elected managing director of the American Gas Association, New York, N. Y. Mr. Wolf was born in Edwardsville, Ill., and was graduated from the University of Illinois with the degrees of bachelor of science, master of science, and electrical engineer. Upon graduation in 1914 he was employed by the State Public Utilities Commission of Illinois, Springfield, as service inspector, later becoming assistant engineer. In 1916 he became affiliated with the Edwardsville (Ill.) Water Company as superintendent. From 1917 until 1919 he served as an officer, United States Army Corps of Engineers. From then until 1921 Mr. Wolf was industrial engineer with Arthur Young and Company, and Griffenhagen and Associates, Ltd., in reorganizing and standardizing engineering and related organizations and units in the United States and Canada. In 1921 he served as assistant chief engineer, Public Service Commission of Maryland, Baltimore, and in 1922 became chief engineer of the commission. In 1929 Mr. Wolf resigned to become assistant to the vice-president of the Central Public Utility Corporation. Four years later he became vice-president of the Consolidated Electric and Gas Company, New York, N. Y., and in 1934 assumed the duties of president of the Central Indiana Gas Company, Muncie, Ind., and associated companies in Indiana. In 1938 he was elected president of the Atlanta Gas Light Company.

John Durwald Miner, Jr. (M '42) manager, aviation engineering, Westinghouse Electric Corporation, Lima, Ohio, has been appointed 1945–46 chairman of the AIEE committee on air transportation. Mr. Miner was born in East Greenwich, R. I., October 3, 1903, and was graduated from Brown University in 1925 with the degree of bachelor of science in electrical engineering. In 1925 he enrolled in the graduate-student course at the Westinghouse Electric Corporation and attended the engineering school and electrical design school. Subsequently, he was appointed design engineer on various types of rotating machinery in the motor division. In 1928 he was transferred to the small-motor division and worked chiefly on the design of rotating equipment for use with radio, particularly aircraft radio. Mr. Miner transferred to Lima when the small-motor division was relocated there in 1937. Two years later he was made section engineer on universal motors, in 1940, section engineer on universal and d-c motors, and section engineer on aircraft equipment in 1941. In 1942 he was named manager of engineering, small-motor division. Two years later in 1944, he was appointed to his present position with the Westinghouse company. Mr. Miner has served on several AIEE committees, including air transportation, technical program, Standards, and award of Institute prizes.

F. L. Rohrbach (A '13, M '28) formerly underground engineer, Washington Water Power Company, Spokane, has retired after completing 38 years of continuous service with that company. Mr. Rohrbach was born in Sunbury, Pa., and was graduated from Pennsylvania State College with a degree in electrical engineering in 1903. After a period of four years in the test department of the General Electric Company he became associated, in 1907, with the Washington Water Power Company as a clerk. He later served as engineer, underground system, and maintenance engineer of substations continuing in charge of underground systems.

Zay Jeffries (M '36, F '42) vice-president, General Electric Company, in charge of chemical department at Pittsfield, Mass., has been chosen to receive the John Fritz Medal for 1946. Mr. Jeffries was born April 22, 1888, at Willow Lake, S. Dak., and received the degrees of bachelor of science and metallurgical engineer from the South Dakota School of Mines, and the degree of doctor of science from Harvard University. From 1911 until 1917 Doctor Jeffries was a member of the faculty of the Case School of Applied Science, Cleveland, Ohio, and later was made a member of the corporation. He has been a consultant for the incandescent-lamp department of the General Electric Company since 1914 and was made technical director in 1936. Doctor Jeffries is a metallurgist of note particularly with regard to nonferrous metals and is a consultant in electrochemical and electrometallurgical work. He has made many contributions on the metallography of tungsten, on the constitution of steel, on the theory of hardening of metals, and on other fundamental subjects. He has published more than 50 works on metallic and nonmetallic engineering materials. He has received the James Douglas Medal from the American Institute of Mining and Metallurgical Engineers, the Sauveur award from the American Society of Metals, the Clamer Medal of the Franklin Institute, and the powder metallurgy medal of Stevens Institute of Technology. Doctor Jeffries, in addition to being an officer in several corporations and past-president of the American Institute of Mining and Metallurgical Engineers, is active in numerous professional societies in engineering and science in the United States as well as in other countries. An account of the award appears elsewhere in this issue.

F. H. Craton (A '31, M '38) formerly manager, industrial haulage division, General Electric Company, Erie, Pa., has been named assistant manager, transportation divisions, Erie Works of the company. Mr. Craton was born in Syracuse, N. Y., and was graduated from Syracuse University as mechanical engineer. He became affiliated with the General Electric Company in 1924.

H. J. Billica (A '36, M '36) formerly district representative, sales department, the Copperweld Steel Company, Glassport, Pa., has been appointed Pacific district manager with headquarters in San Francisco, Calif. Mr. Billica joined the company in 1943 after serving as senior priority adviser in the power division, Office of War Utilities of the War Production Board, Washington, D. C. Prior to that he had been with the Indiana Steel and Wire Company, Muncie.

J. S. Murray (A '21, M '31) formerly chief electrical engineer, Follansbee (W. Va.) Steel Corporation, has been appointed Pittsburgh, Pa., district manager, Alliance (Ohio) Machine Company. A native of Amsterdam, N. Y., he has been associated with the Follansbee Company since 1921. In 1943 he was elected national treasurer of the Association of Iron and Steel Engineers.

W. H. Reed

J. D. Miner, Jr.

Zay Jeffries

L. N. McClellan (A '14, F '38) chief electrical engineer, United States Bureau of Reclamation, Denver, Colo., has been appointed assistant chief engineer, electrical and mechanical division of the bureau. Mr. McClellan was graduated from the University of Southern California in 1911 with a bachelor-of-science degree in electrical engineering. First employed by the Bureau of Reclamation in August 1911 he served in various capacities. He spent a year in the United States Army Corps of Engineers during World War I, and in 1924 was employed in the operating department of the Southern California Edison Company. Since 1924 he has been chief electrical engineer, Bureau of Reclamation, in charge of design, construction, and operation of all power plants, pumping plants, transmission lines and substations built and operated as federal irrigation projects. Mr. McClellan is the author of papers on the Boulder Dam project published by the Institute, and was a member of the AIEE committee on power transmission and distribution, 1933–36, and a vice-president 1937–39.

L. S. Wing (A '27, M '34) a member of the Federal Power Commission, Washington, D. C., has been appointed regional engineer at San Francisco, Calif. Mr. Wing was graduated from the South Dakota State College of Agriculture and Mechanical Arts and in 1916 took the student course with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Subsequent positions were with the Consumers Power Company, Jackson, Mich.; the Great Western Electro-Chemical Company, San Francisco, and the American Smelters and Refining Company, Tacoma, Wash. He has been with the Federal Power Commission since 1934.

James DeKiep (M '43) formerly manager, a-c motor engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed chief engineer in charge of electrical and mechanical design and development. Mr. DeKiep was graduated from the University of Michigan in 1927 with a bachelor-of-science degree in electrical engineering. He became associated with the Westinghouse company in 1929.

OBITUARY • • • • •

Peder Reinhardt Pedersen (A '23) formerly designer, electrical department, Phelps Dodge Corporation, New York, N. Y., died recently. Mr. Pedersen was born in Skaade, Denmark, October 4, 1893, and was graduated from the Institute of Electrical Engineering at Aarhus, Denmark, in 1918. From 1918 to 1920 he was engaged in designing electric machinery in Copenhagen, Denmark. Later he served the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., Stone and Webster, Boston, Mass., and, on many occasions in his career, was associated with Sanderson and Porter, engineers, New York, N. Y. From 1933 to 1937 he was with the Braden Copper Company and the Kennicott Company, both in Rancagua, Chile, South America. In 1939 Mr. Pedersen was a designer for Archer E. Wheeler, New York, N. Y.

Malcolm MacLaren (A '05, M '25) professor emeritus, Princeton (N. J.) University, died September 24, 1945. Professor MacLaren was born in Annapolis, Md., in 1869, and was graduated from Princeton University in 1890 as a bachelor of arts, in 1892 as an electrical engineer, and in 1893 as a master of arts. From 1893 until 1908 he was associated with the Westinghouse Electric and Manufacturing Company both in the United States and in England. In the latter year he became chairman of the department of electrical engineering at Princeton University and held that post until his retirement in 1937. During World War I he served as a major with the United States Army Corps of Engineers, and was assigned to the power section of the War Industry Board. Professor MacLaren was the author of "The Rise of the Electrical Industry During the Nineteenth Century." He served on the following AIEE committees: superpower system, 1920–21; education, 1924–25; Lamme Medal, 1933–36.

Beshara Elian Battit (A '35) captain, Air Corps, United States Army, was killed in line of duty with the United States Strategic Air Forces in France, October 11, 1944. Captain Battit was born in Boston, Mass., and was graduated from the Massachusetts Institute of Technology with a degree in electrical engineering in 1934. Following graduation he became affiliated with the Massachusetts Institute of Technology as an assistant instructor. Later he joined the A. C. Neilson Company, Chicago, Ill., and then Jackson and Moreland, engineers of Boston. He entered the military service on February 7, 1942, and before going overseas was stationed at Camp Murphy, Fla., Boston; Fort Monmouth, N. J.; and Wright Field, Ohio.

Robert Otjen Buehner (M '36, F '43) electrical engineer, Weatherhead Company, Cleveland, Ohio, died July 23, 1945. He was born in Milwaukee, Wis., January 9, 1903. Employed by Allis-Chalmers Manufacturing Company, Milwaukee, from 1923 to 1927, Mr. Buehner, in the latter year, accepted a position with the American Steel and Wire Company, Waukegan, Ill., as Chicago district electrical engineer. He was made assistant district engineer in 1929 and company electrical engineer in 1943. In 1942 he was transferred to Joliet, Ill., and in 1943 to Cleveland. Mr. Buehner remained with the American Steel and Wire Company until January 1945 when he entered the employ of the Weatherhead Company.

Myron Creese (A '07, M '40) professor of electrical engineering, University of Maryland, College Park, died recently. He was born in Red Rock, Pa., July 26, 1883, and was graduated from the Pennsylvania State College, State College, Pa., with the degrees of bachelor of science in electrical engineering in 1905 and electrical engineer in 1906. In 1907 he was appointed instructor in electrical engineering and physics at the Maryland State College, then named the Maryland Agricultural College. In turn he became assistant professor, associate professor, and professor. Early in his career he spent summers working for the General Electric Company at Chester, Pa., and for the Westinghouse Electric and Manufacturing Company, at East Pittsburgh, Pa.

MEMBERSHIP • • •

Recommended for Transfer

The board of examiners, at its meeting of October 18, 1945, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the secretary of the Institute.

To Grade of Fellow

Burrows, C. R., chairman, Committee on Propagation, N.D.R.C., member of tech. staff, Bell Telephone Labs., Inc., New York, N. Y.
Cowan, F. A., trans. engr., American Tel. & Tel. Co., New York, N. Y.
Dee, T. C., gen. supt., Ohio Edison Co., Akron, Ohio.
Fox, J. C., elec. engr., Virginian Railway Co., Princeton, W. Va.
Marbury, R. E., mgr., capacitor sec., Westinghouse Electric Corp., E. Pittsburgh, Pa.
Stansel, N. R., spec., ind. engg. div., General Electric Co., Schenectady, N. Y.
Tyvand, J. A., chief engr., Wisconsin Gas & Electric Co., Racine, Wis.

7 to grade of Fellow

To Grade of Member

Anderson, L. W., engr., General Electric Co., Louisville, Ky.
Barrell, R. W., Jr., locomotive engg. div., General Electric Co., Erie, Pa.
Bates, H. H., dist. plant supt., American Tel. & Tel. Co., Cincinnati, Ohio.
Biele, C. E., Comdr., USNR, div. of electronics, CNO, Navy Dept., Washington, D. C.
Bruce, W. C., equip. maint. engr., Southern California Tel. Co., Los Angeles, Calif.
Bumpas, W. E., gen. elec. foreman, U. S. Bureau of Reclamation, Kremmling, Colo.
Coone, L. A., aircraft apparatus, General Electric Co., Atlanta, Ga.
De Villiers, I., head office engr., Electricity Supply Comm., Johannesburg, S. Africa.
DiToro, M. J., senior elec. engr., Hazeltine Electronics Corp., Little Neck, N. Y.
Emmerling, E. J., Captain, Signal Corps, U. S. Army, Watson Laboratories, Red Bank, N. J.
Fleming, J. G., research engr., Bristol Company, Waterbury, Conn.
Fosholt, S. K., assoc. engr., Stanley Engineering Co., Muscatine, Iowa.
Fulton, R. A., Jr., engr., Western Electric Co., Kearny, N. J.
Haley, J. L., supt., elec. meter dept., Memphis Light, Gas & Water Div., Memphis, Tenn.
Hansen, A., Jr., instrument engr., General Electric Co., Lynn, Mass.
Hill, D. A., commercial engr., Ohio Public Service Co., Cleveland, Ohio.
Jagger, C. A., elec. engg., General Electric Co., Schenectady, N. Y.
Leightman, H., cons. engr., Sterick Bldg., Memphis, Tenn.
Mascaro, W. O., elec. engr., Atlantic Refining Co., Philadelphia, Pa.
Miller, J. B., assoc. prof. of elec. engg., Bucknell University, Lewisburg, Pa.
Moran, J. M., research assoc., Harvard University, Cambridge, Mass.
Morgan, W. D., test engr., Memphis Light, Gas & Water Div., Memphis, Tenn.
Olive, J. M., chief street lighting engr., Memphis Light, Gas & Water Div., Memphis, Tenn.
Ratajczak, F. X., elec. engr., Gilbert Associates, Inc., Reading, Pa.
Sachs, S. C., owner, S. C. Sachs Co., St. Louis, Mo.
Sievers, G. F., Sr., elec. engr., Navy Department, Washington, D. C.
Smith, D. S., junior research engr., National Research Council, Ottawa, Can.
Suski, H. M., project engr., Naval Research Laboratory, Anacostia Sta., Washington, D. C.
Sussman, H. W., elec. engr., Columbia Electric Mfg. Co., Cleveland, Ohio.
Wall, H. R., Lieut., USNR, Search Radar Section, Navy Yard, South Boston, Mass.
Ward, J. E., Jr., elec. engr., Naval Ordnance Lab., Navy Yard, Washington, D. C.
Zacherle, B. H., elec. engr., United Engineers & Constructors, Inc., Philadelphia, Pa.

32 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before December 15, 1945, or February 15, 1946, if the applicant resides outside of the United States or Canada.

To Grade of Member

Abbott, A. C. (Re-election), The Shawinigan Water & Power Co., Montreal, P. Q., Canada
Brennan, M. J., E. J. Electrical Corp., New York, N. Y.
deNagy, L. G., USED, Oak Ridge, Tenn.
de Neuf, D. K., Raytheon Mfg. Co., New York, N. Y.
Edick, R. S. (Re-election), George S. Armstrong & Co., Inc., New York, N. Y.
Eisner, J. H., Auburn Spark Plug Co., Inc., Auburn, N. Y.
Farquhar, W. A., Lt. USNR, Office of Chief of Naval Operations, Washington, D. C.
Fredlund, E. F. G., AB Elektrolux's Laboratory, Stockholm, Sweden
Gibbs, J. T., Volunteer Electric Cooperative, Decatur, Tenn.
Gove, R. D., Cutler Hammer, Inc., Milwaukee, Wis.
Grieg, M. H. (Re-election), Penna. Power & Light Co., Shenandoah, Pa.
Grogan, R. M., Long Island Lighting Co., Roslyn, L. I., N. Y.
Hirsh, D. (Re-election), Hirsh Electric Co., Houston, Tex.
Horvath, J., Jr., General Electric Co., Pittsfield, Mass.
Klauder, L. T. (Re-election), Louis T. Klauder & Associates, Philadelphia, Pa.
Lamb, M. D. (Re-election), Commonwealth Edison Co., Chicago, Ill.
Lamont, L. M., Westinghouse Electric Corp., Boston, Mass.
Lang, K. A., Lindberg Engineering Co., Chicago, Ill.
Leadbetter, J. W., Univ. of Notre Dame, Notre Dame, Ind.
Legate, R. M., Central Technical Power Board, Calcutta, India
Lose, W. E. (Re-election), The Detroit Edison Co., Detroit, Mich.
Marrotte, L. H. (Re-election), Hydro-Quebec, Montreal, P. Q., Canada
McCaughrin, W. O., Supreme Power Supplies, Ltd., Mimico, Ont., Canada
McDougald, A. D. (Re-election), 12th Naval Dist. Headquarters, San Francisco, Calif.
McFarland, G. L., General Electric Co., Schenectady, N. Y.
Montgomery, A. W., Standard Telephones & Cables, Ltd., London, England
Moulton, B. S. (Re-election), The Commonwealth & Southern Corp., Jackson, Mich.
Myers, V. A., National Carbon Co., Inc., Cleveland, Ohio
Neale, R. D., Canterbury University College, Christchurch, N. Z.
Newton, A. H. (Re-election), Signal Corps, U. S. Army, Philadelphia, Pa.
Niemann, W. J. (Re-election), Commonwealth Edison Co., Chicago, Ill.
Rupp, J. L., National Battery Co., Depew, N. Y.
Shurtz, M. Maj., A.C., A.P.O., New York, N. Y.
Van Kirk, R. W., General Elec. Co., Beaumont, Tex.
Waghorne, A. C., Southwestern Public Service Co., Denver City, Tex.
Waldorf, H. J., Thomson's Electrical Works, Montreal Que., Can.
Ware, D. H., General Electric Co., Schenectady, N. Y.
Willson, G., Cable Works of Telefonaktiebolaget L M Ericsson, Alvsjo, Sweden

38 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Cotton, F. E., Jr., Naval Training School, M.I.T., Boston, Mass.
Fenneus, S. M., Mass. Inst. of Tech., Cambridge, Mass.
Fischer, W. O., Simplex Wire & Cable Co., Cambridge, Mass.
Hammond, G. H., Tufts College, Medford, Mass.
Johnson, R. A., Simplex Wire & Cable Co., Cambridge, Mass.
Neal, F. M., Corning Glass Wks., Corning, N. Y.
Stanfield, T. O., General Electric Co., Pittsfield, Mass.

2. Middle Eastern

Bracken, J. M., Phila. Navy Yard, Philadelphia, Pa.
Carpenter, S. L., Phila. Elec. Co., Norristown, Pa.
Dosey, H. W., U. S. War Dept., Cleveland, Ohio
Fancher, R. L., Jr., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Fryer, L., Leeds & Northrup Co., Philadelphia, Pa.
Fulton, L. F., Lt. (sg) U.S.M.S., Turbo-Elec. School, Chester, Pa.
Gealt, A. E., Browa Instrument Co., Philadelphia, Pa.
Jacobs, O. R., Lear, Inc., Piqua, Ohio
Kettlehake, M. W., American Tel. & Tel. Co., Dayton, Ohio
Kramer, J. F., Lt., Sig. C., U.S.A., Cleveland, Ohio
Murphy, R. J., Bureau of Ships, Navy Dept., Washington, D. C.
Nonneman, H. S., Dayton Power & Light Co., Dayton, Ohio
Phillips, J. D., General Electric Co., Erie, Pa.
Sherman, C. W., 111, AAF Air Tech. Serv. Cmd., Dayton, Ohio
Summers, R. M., Leeds & Northrup Co., Philadelphia, Pa.
Towle, P. A., Leeds & Northrup Co., Philadelphia, Pa.
Wilbur, J. C. (Re-election), General Electric Co., Akron, Ohio
Wilhoit, G. D., Westinghouse Electric Corp., Huntington, W. Va.
Williams, D. R., Naval Ordnance Laboratory, Washington, D. C.
Wise, J. (Re-election), Baltimore & Ohio Railroad Co., Toledo, Ohio

3. New York City

Bock, R. O., Arma Corp., Brooklyn, N. Y.
Bolton, W. J., Queens Borough Gas & Elec. Co., Far Rockaway, N. Y.
Challenger, A., Major, U. S. Army, Sig. Corps Engg. Labs., Bradley Beach, N. J.
Cunniffe, T. G., Ensign, U. S. Naval Reserve, New York, N. Y.
Davis, S., Otis Elevator Co., New York, N. Y.
Pasha, R. C., Bell Telephone Labs., New York, N. Y.
Figiel, W. J., Otis Elevator Co., New York, N. Y.
Gambuzza, M. C., Todd Shipyard Corp., Hoboken, N. J.
Goldberg, H. S., Cole Electric Products Co., Long Island City, N. Y.
Kelly, J. M., H. A. Fraser, Inc., New York, N. Y.
Kenny, J. A., Haseltine Electronics Corp., Bayside, L. I., N. Y.
Magee, W. A., Capt., Sig. Corps Engg. Labs., Bradley Beach, N. J.
Martins, A. S., Bell Telephone Labs., New York, N. Y.
Mascharka, L. A. (Re-election), Westinghouse Electric Int. Co., New York, N. Y.
Ridpath, L. W., Federal Telephone & Radio Corp., Newark, N. J.
Shepard, W. H., Ens., USNR, c/o F.P.O., New York, N. Y.
Stefanell, R., Federal Telecommunications Labs., New York, N. Y.
Streiinger, J. C., Ebasco Services, Inc., New York, N. Y.
Willis, E. S. (Re-election), Bell Telephone Labs., New York, N. Y.
Wulfken, A. J. (Re-election), Amer. Transformer Co., Brooklyn, N. Y.

4. Southern

Calvert, R. C. M., Jr., Newport News Shipbuilding & Dry Dock Co., Newport News, Va.
Conoley, J. J., Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Field, B. W., T/4, Tennessee Eastman Corp., Oak Ridge, Tenn.
Jenkins, J. E., Armature Winding Co., Charlotte, N. C.
Kirk, R. C., Kyle Corp., Atlanta, Ga.
Nuttall, E. D., Southwestern Gas & Elec. Co., Shreveport, La.
Phillips, C. H., Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Stouse, L. E., Jr., Laurinburg-Maxton AAB, Maxton, N. C.
Weiss, R. L., Lieut., USAAF. Maxwell Field, Montgomery, Ala.
Wortman, W. J. (Re-election), Duke Power Co., Charlotte, N. C.
Zehnder, R. J., Navy Yard, Charleston, S. C.

5. Great Lakes

Atwood, A. R., Wisconsin Electric Power Co., Milwaukee, Wis.
Blank, H. F., Louis Allis Co., Milwaukee, Wis.
Burroughs, H. A., Automatic Electric Co., Chicago, Ill.
Carraway, B. T., Swift & Co., Chicago, Ill.
Daniel, H. K., Chrysler Corp., Highland Park, Mich.
Doehler, G. C., Hevi Duty Electric Co., Milwaukee, Wis.
Evans, N. A., Harnischfeger Corp., Milwaukee, Wis.
Gabriel, N. H., Defoe Shipbuilding Co., Bay City, Mich.
Grabowski, L. R., Defoe Shipbuilding Co., Bay City, Mich.
Hall, J. L., Defoe Shipbuilding Co., Bay City, Mich.
Halleck, M. C., General Electric Co., Fort Wayne, Ind.
Henderson, J. E., Carnegie-Illinois Steel, Chicago, Ill.
Hoffman, W. W. (Re-election), Wisconsin Elec. Power Co., Milwaukee, Wis.
Kowal, C. F., Louis Allis Co., Milwaukee, Wis.
Kremski, E. S., Louis Allis Co., Milwaukee, Wis.
Lemmer, F. R., Louis Allis Co., Milwaukee, Wis.
McDaniels, R. R., Carnegie-Ill. Steel Corp., Chicago, Ill.
Mehta, T. N., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Rahrig, G. O., Consumers Power Co., Jackson, Mich.
Reed, W. H., Commonwealth Edison Co., Chicago, Ill.
Robinson, F. J., Ill. Bell Tel. Co., Chicago, Ill.
Rosenberg, F. W., Louis Allis Co., Milwaukee, Wis.
Roush, D. N., Westinghouse Elec. Corp., Chicago, Ill.
Shafer, M., The Commonwealth & Southern Corp., Jackson, Mich.
Smeaton, R. W., Allis Chalmers Mfg. Co., West Allis, Wis.
Ten Bick, R. A., General Motors, Indianapolis, Ind.
Tower, H. A., Central Ill. Public Serv. Co., Springfield, Ill.
Ulbrich, W. J., Louis Allis Co., Milwaukee, Wis.
Umaine, M. B., Western Elec. Co., Chicago, Ill.
Waldron, V. L., Kuhlman Electric Co., Bay City, Mich.
Weidner, E. G., Louis Allis Co., Milwaukee, Wis.
Wichman, J. A., Louis Allis Co., Milwaukee, Wis.
Wightman, F. R., Public Service Co. of No. Ill., Chicago, Ill.
Winstrode, W. C., General Electric Co., Fort Wayne, Ind.
Wise, E. G., Westinghouse Elec. Corp., Chicago, Ill.
Wood, R. A., Line Material Co., So. Milwaukee, Wis.
Ziegler, O. J., Kuhlman Electric Co., Bay City, Mich.

6. North Central

Hobday, L. T., Mountain States Tel. & Tel. Co., Denver, Colo.

7. South West

Arnold, J. B., Arnold-Stubenbord, Inc., San Antonio, Texas
Basham, R. B., Consolidated-Vultee Aircraft Corp., Ft. Worth, Texas
Blanton, T. G., Wilson Electrical Equipment Co., Houston, Texas
Chimene, I. E., 2102 Kingston Drive, Houston, Texas
Dryer, E. D., Missouri Public Service Corp., Warrensburg, Mo.
Hambrick, W. G., Hambrick Electric Co., Houston, Texas
Herrington, C. R., Southwestern Public Service Co., Amarillo, Texas
Hoffmeister, R. G., Texas Power & Light Co., Dallas, Texas
Hughes, H. L., Public Service Co., Lawton, Okla.
King, L. L., Southwestern Bell Telephone Co., Oklahoma City, Okla.
Luckey, D. E., Texas Electric Service Co., Ft. Worth, Texas
McNary, T. H., Jr., Boeing Airplane Co., Wichita, Kans.
Peevey, J., Supervisor of Shipbuilding, U.S.N., Orange, Texas
Seip, N. W., General Electric Co., St. Louis, Mo.
Shaffer, B. W., Southwestern Bell Telephone Co., Tulsa, Okla.
Smith, C. A., Oklahoma Gas & Electric Co., Oklahoma City, Okla.
White, M. H., Dallas Power & Light Co., Dallas, Texas

8. Pacific

Barrington, J. D., General Electric Co., San Francisco, Calif.
Caruthers, R. W., General Electric Co., San Francisco, Calif.
Chapin, W. A. Jr., Lt. U.S.N.R., c/o F.P.O., San Francisco, Calif.
Davis, W. L., Southern Calif. Telephone Co., Los Angeles, Calif.
Gusman, C. C., Jr., Lt., USNR, U. S. Naval Hospital, Mare Island, Calif.
Harris, E. B., U. S. Naval Air Station, Alameda, Calif.
McDaniel, G., Consolidated Engineering Corp., Pasadena, Calif.
Springfield, C. E., Shell Oil Co., Martinez, Calif.
Swanson, N. E., Goodyear Synthetic Rubber Corp., Torrance, Calif.
Van Nice, J. H., Consolidated-Vultee Aircraft Corp., San Diego, Calif.
Wessling, J. R., U. S. Naval Air Station, Alameda, Calif.

9. North West

Bracchi, R. R., General Elec. Co., Portland, Ore.
Hilke, N. H., International Business Machines Corp., Butte, Mont.
Hill, L. E., Puget Sound Power & Light, Bremerton, Wash.
Palmquist, J. A., Montana Power Co., Great Falls, Mont.
Parker, F. S., General Elec. Co., Portland, Ore.

10. Canada

Allen, G. Y. R., Osborne Electric Co., Ltd., Toronto, Ont., Canada
Cole, R. A., Elec. Lt., R.C.N.V.R., Ottawa, Ont., Canada
Prout, S. M., British Admiralty Technical Mission, Ottawa, Ont., Canada

Elsewhere

Dai, C. C., Taeliusing Elec. Works, N.R.C., China
Jamieson, D., Public Works Dept., Auckland, New Zealand
Lundholm, R. O., Royal Board of Waterfalls, Stockholm, Sweden
Mansson, H., Swedish Association of Electricity Works, Stockholm, Sweden
O'Donnell, C. V., Electricity Supply Board, Dublin, Ireland
Reguera, F. J. J. M., Nicaro Nickel Co., Nicaro, Oriente, Cuba
Robinson, J. (Army), 67 Kemp St., Manchester, Lancs., England
Silva, F. S., Nueva Cia. Electrica de Chapala, S. A., Guadalajara, Jal., Mexico
Steventon, P. A., Air Ministry Directorate of Works, London, England
Swayambu, S. L., Office of the Electrical Commissioner, Calcutta, India
Zabludowski, G., General Electric Co., Rio de Janeiro, Brazil, S. A.

Total to grade of Associate
United States and Canada, 132
Elsewhere, 11

OF CURRENT INTEREST

Third Report of National Patent Planning Commission

The basic concept of both patents and copyrights is the assurance to the individual creators of the new and useful an adequate protection of their intellectual property against piracy. The National Patent Planning Commission in its third report issued under date of September 8, 1945, rejects proposals for revision of the patent system of the United States involving a departure from the principles upon which it is founded and by the "effectuation of which it has furthered the nation's industrial and social improvement." This is the philosophy in the main of this report of the Commission which is a résumé of recommendations already made for the information of the President, and a summary of the main subjects and problems now under consideration. A study of the existing patent laws was made as a result of a directive of the President on April 20, 1945, to the Secretary of Commerce to form a committee to offer recommendations respecting legislative proposals to be laid before Congress.

With reference to its first report the Commission advised the adoption of several remedial courses, such as the creation of a single court of patent appeals; establishment by Congress of a reasonable, understandable test of patentability; reference back to the Patent Office of technical questions raised in suits for infringement of patents; all contracts relative to patents be publicly recorded in the United States Patent Office; a term of a patent shall not extend beyond 20 years from the date of the filing of an application, and that the present statutory term of 17 years be retained except in those cases in which more than the three years were consumed in its procurement; simplification of appellate procedure; opportunity afforded the public to challenge the validity of a patent within six months after its grant; creation of a public register, and ruling out the proposal for general compulsory licensing of patents.

In its second report the Commission made recommendations concerning the treatment of Government-owned patents, and inventions of Government employees and contractors.

Currently, the Commission has under consideration the following problems:

1. Elimination or simplification of accounting proceedings to reduce the cost of litigation.
2. Enlargement of the power of the Commissioner of Patents.
3. Incorporation in the tax laws of provisions designed to induce investment of capital in new enterprises, particularly based on new inventions.
4. Reduction of cost and simplification of procedure of patent litigation.
5. Clarification and extension in statutory form of the power of a court to compel the granting of licenses on reasonable terms in the case of a defendant's conviction for violation of the antitrust laws.
6. Greater observance of the presumption of validity of patents.
7. Provision at the Patent Office with more adequate facilities.
8. Making possible the exploitation of so-called use patents, that is, patents involving the use of unpatented materials.
10. Correction of patents for improper joinder or non-joinder of inventors.
11. Granting of patents to foreigners.
12. Problems relating to the stimulation of discovery and invention in addition to the patent laws.

Predoctoral Fellowships Offered by National Research Council

The National Research Council, Washington, D. C., announces that it is now ready to receive nominations and applications for the predoctoral fellowships in the natural (mathematical, physical, and biological) sciences which it is administering under a grant from the Rockefeller Foundation. These fellowships are intended to assist young men and women, whose graduate study has been prevented or interrupted by the war, to complete their work for the doctorate.

The annual stipend will be $1,200 for single persons and $1,800 for married men. In general it is expected that each recipient will spend at least 11 months per year on academic work. An additional allowance up to $500 per year will be made for tuition fees. Fellowships granted to individuals who are eligible for educational support under the "G.I. Bill of Rights" will be at such stipends as to bring the total income from these two sources to that which would be received at the afore-mentioned rates.

Prospective candidates for these fellowships are urged to apply at once. Information may be obtained by writing to the secretary, committee on predoctoral fellowships, National Research Council, Washington 25, D. C.

Electronics Research at Naval Laboratory

To strengthen research for the naval organization four new scientific divisions dealing with electronics have been established at the Naval Research Laboratory, Washington, D. C. These new divisions, set up by Rear Admiral A. H. Van Keuren, director of the laboratory, will be organized along lines found essential as a result of war experience. They will bring high-grade technical talent into closer contact with fleet operating and maintenance problems. The activities of the laboratory formerly were contained in a single radio division under Doctor A. Hoyt Taylor of Chicago, Ill., who has been named chief consultant and co-ordinator for electronics. The four men appointed as heads of the new divisions are the following: Doctor Robert M. Page, St. Paul, Minn., Doctor John M. Miller, Hanover, Pa., L. A. Gebhard, Buffalo, N. Y., and R. A. Gordon, Hyattsville, Md.

Engineers Would Limit Germany's Industrial Control

Prohibition or control of five war potentials to prevent German rearmament is recommended in a report, "Industrial Disarmament of Aggressor States (Germany)," by the National Engineers Committee of the Engineers Joint Council on which is representation from five engineering societies including AIEE.

Its program for control of German industry based on a year's study by 35 leading engineering and technological specialists was submitted under date of September 21, 1945, to the State, War, and Navy Departments, Commanding General of Army Service Forces, Foreign Economic Administration, since dissolved, and Lieutenant General L. D. Clay, deputy to General Dwight D. Eisenhower, for the Office of Military Government formerly known as the United States Group Control Council for Germany.

Working within the framework of the Yalta and Potsdam agreements, the engineering group concludes that assurance that Germany will keep the peace requires institution and maintenance of all effective controls of power production and distribution and industrial plant construction to:

1. Prohibit synthetic fixation of nitrogen.
2. Prohibit production of synthetic liquid fuels.
3. Prohibit production of aluminum.
4. Prohibit development and use of atomic energy.
5. Limit the capacities and production of steel and steel-products plants.

In addition the program involves the control of scientific research and of economic subsidies from the State.

On the subject of electric power the report recommended that a comprehensive postwar control of German industry be based on a system of energy allocation. Specifically the report states:

> The fundamental factor is energy, since it is required in one form or another to operate all processing equipment for the transformation of all raw materials into finished goods. Therefore, regulations based on energy are so inclusive that all industrial operations fall within their scope.
>
> Control of power distribution through allocation of all coal distribution, while fundamentally effective, would be cumbersome, a handicap to peaceful development, and would require a considerable staff. A rigid control of electric-power distribution is therefore important to ensure compliance and regulation of German industry.
>
> The specific details of electric-power allocation must be formulated by the Office of Military Government possessing firsthand information of the requirements of German industrial and domestic activities. It is assumed that after productive limitations, consistent with the recommendations herein contained, have been determined for German industry, it will be relatively easy to ascertain the energy requirements to supply industrial and domestic needs. All excess capacity above that allotted to a given district, including installations in industrial plants, should be removed and all of the contiguous auxiliaries, building foundations, and other services should be removed or destroyed. It should be realized, however, that the electric-power industry in Germany cannot and should not be used as the sole means of controlling other industries for disarmament purposes. Reports on the use of electric energy by individual manufacturing plants cannot be relied upon as a definite indication of the magnitude and nature of manufacturing operations.

In September 1944, the presidents of the American societies of electrical, civil, mining and metallurgical, mechanical, and chemical engineers in a joint signed statement declared that the proposed destruction of Germany's entire industrial plant is economically unsound and contains the seeds of a new war. The full text of that statement has been published. (*EE, Nov '44, p 393–94*)

Electronics Plant Planned at Syracuse

A university of industry soon will become a reality on 155 acres of ground outside Syracuse, N. Y., as the General Electric Company begins the construction of its new $10,000,000 electronics headquarters plant. Laid out and landscaped like a college campus, the new plant will be known offically as General Electric's "Electronics Park." Here employees will work under the most modern conditions in well-lighted, air-conditioned factory buildings and offices, surrounded by an inspiring park-like atmosphere and reached by modern highways leading to and through the plant.

Doctor Walter Baker (A '19, M '41), vice-president of the company discussing the bright future for electronics said that as chemistry is not limited to plastics or synthetic rubber, neither is electronics limited to radio, communications, or radar; it will contribute to numerous fields and in some cases create new industries, like television.

X-Ray Diffraction Clinic Completed at Polytechnic Institute

Nineteen physicists, engineers, metallurgists and research chemists in industry recently completed a clinic on the industrial application of X-ray diffraction at the Polytechnic Institute of Brooklyn, Brooklyn, N. Y. These men made in daily laboratory sessions an intensive use of the available equipment for the study of all standard techniques in this work. In addition, they had an opportunity to observe the pioneer work in the study of low-angle scattering carried out by Doctor I. Fankuchen, adjunct professor of crystal chemistry, with Doctor Herman F. Mark, international authority on high polymers who heads the high polymer research bureau at the Polytechnic Institute.

The polytechnic X-ray diffraction laboratory contains several new instruments developed by Doctor Fankuchen, who conducted the clinic. One is a microcamera, designed for the study of very small specimens. Another is a pump designed on a simple principle to permit the continuous flow of solutions in front of X-ray beams. Other equipment in the laboratory includes four complete X-ray units, powder cameras of all types, focussing cameras, X-ray monochromators, low-angle scattering cameras, apparatus for single crystal study, and a new equi-inclination Weissenberg goniometer.

Fourteen practicing chemists from leading industrial firms recently completed an intensive study of a number of modern techniques of polymer chemistry at the Institute. Under the direction of Doctor Mark, the clinic was organized as the first move to make research facilities of the Institute available to industrial chemists in a manner not possible in general graduate courses.

Bibliography on Social Impact of Science

As an aid in the study of legislation on science now before Congress, the Subcommittee on War Mobilization of the Senate Military Affairs Committee, issued on September 9, 1945, a select bibliography on "The Social Impact of Science." The bibliography has been prepared by the Library of Congress. It lists more than 500 titles of books, pamphlets, articles, and Congressional bills and reports dealing with the social and economic problems arising from scientific progress. A special section covers the available literature on atomic power, including several volumes not yet published.

Grants for Collegiate Research

Grants amounting to $2,500,000 for postwar collegiate research have been offered by the Research Corporation, New York, N. Y., a nonprofit organization devoted to advancing research and technology by use of revenues from inventions assigned to it by public-spirited inventers. These grants will enable talented young scientists engaged for the most part in war research to undertake at universities and colleges research of peacetime importance in pure science, especially engineering, chemistry, physics, and mathematics.

A five-year program was announced by Doctor J. W. Barker (M '26, F '30) acting president, who is back with the corporation and has returned to Columbia University, New York, N. Y., as dean, faculty of engineering, and professor of electrical engineering. He had been serving as special assistant to the Secretary of the Navy. Included on the special committee which will make the grants are Doctor Barker, and W. D. Coolidge (A '10, M '34) director of research laboratory, General Electric Company, Schenectady, N. Y. Preference in making these grants will be given, other factors being equal, to smaller institutions and those of more limited financial resources.

Cultural Agency in State Department. The State Department of the United States is creating the Office of International Information and Cultural Affairs. Its objectives are stated to be the co-ordination and direction of policies and activities in the field of international information and cultural affairs, the development of policies and programs promoting freedom of information among peoples, and the furtherance of international exchanges of persons, knowledge, and skills.

An "Engineer-in-Training" License. A new "Professional Engineers Registration Law" was passed recently by the Pennsylvania State Legislature. The innovation in this act is the classification "Engineer-in-Training." This provision is made so that an applicant can take his examination in fundamental engineering principles when he is best fitted to do so. If an applicant is a graduate of an approved engineering institution, he is granted a certificate of engineer-in-training without an examination. Thereafter, all he needs to pass, after he has had the required four years of experience, is an examination in engineering practice. Applicants who are not graduates can take these examinations separately or at the same time. The years of experience required of a graduate have been increased to four to meet a similar requirement of all other states. The Act will become effective on June 30, 1946.

Labor Bulletin in New Approach. Out of the 25-year-old *Industrial Bulletin* issued by the State of New York Department of Labor, Albany, has evolved a modern news-and-picture magazine with the September issue. This, too, is a report to the people of the state but with pictures and with quick reading on the labor laws explained in terms of the people. The reports and surveys carried in the former technical bulletin will be relayed in other form to all who find use for them.

OTHER SOCIETIES •

Proposed Simplified Practice For Hot-Rolled Carbon-Steel Structural Shapes

A voluntary simplified practice recommendation for hot-rolled carbon-steel structural shapes, as proposed by the technical committee on carbon-steel plate and structural shapes, of the American Iron and Steel Institute, was made available, during September 1945, to all interests, for their consideration, comment, and approval. The proposal, announced by the division of simplified practice of the National Bureau of Standards, contains 18 tables, covers the nominal sizes and weights per linear foot of sections, beams, stanchions, joists, channels, angles, tees, and zees. Sections and angles used in carbuilding and shipbuilding are included.

Vast Industrial Achievements Foreseen. Accomplishments in the realms of electricity and aviation that would have sounded fantastic before the war were told to members of the Colorado Society of Engineers at its recent midsummer meeting in Denver, Colo. A. C. Streamer (A '10, M '41), vice-president of the Westinghouse Electric Corporation, East Pittsburgh, Pa., and president of the National Electrical Manufacturers Association, stressed the present employment responsibility of industry. He said that the chief purpose in attaining a high-employment goal is to achieve a high standard of living, and that is attained by greater production per man through increased efficiency of machinery and methods and greater personal proficiency. Further he declared that the expected postwar air service pictured by the Air Transport Association is an astounding program. With cruising speeds of more than 300 miles an hour incorporated in many of the new models, the time for crossing the continent would be cut way below the 12- to

14-hour schedules now being regularly flown. Among developments for the more distant future was the turbo-jet power plant, which would provide speeds approaching that of sound.

Prosthetic Devices for Disabled Veterans. Mechanical driver aids for disabled veterans have been developed successfully by engineers of the Society of Automotive Engineers, New York, N. Y. Following a request from the American Society of Motor Vehicle Administrators, a special technical subcommittee of the SAE War Engineering Board started to work on the project, with the result that today Army surgeons report the great majority of injured veterans will be able to drive efficiently and safely. The aids will permit veterans with artificial limbs to operate passenger cars and light trucks. They supplement automatic clutches, drives, and transmissions. For veterans whose legs have been amputated they make it possible to operate the vehicle by hand. For those with artificial hands or arms, they make it possible to manage the controls more easily whether by hand or foot.

Behavior of Dielectrics Discussed. At the September meeting of the Cedar Rapids, Ia., section of the Institute of Radio Engineers R. F. Field (M '40) engineer, General Radio Company, Cambridge, Mass., presented a paper entitled, "The Behavior of Dielectrics Over Wide Ranges of Frequency, Temperature, and Humidity." Supplementing his talk with slides, Mr. Field outlined the theoretical and mathematical aspects of the subject, and demonstrated that such behavior can be predicted to a first approximation when only a few parameters are known.

Welding Officers Meet. A meeting of the national officers, board of directors, and committee chairmen of the American Welding Society was held in New York, N. Y., on October 18, 1945. This group presented the society prizes, medals, and other awards which have been given in past years at the opening sessions to those who made outstanding contributions in the advancement of the science and art of welding.

Aeronautical Institute Will Move. The Institute of Aeronautical Sciences, Inc., publisher of *Aeronautical Engineering Review*, has acquired property for a new headquarters at 2 East 64th Street, facing Central Park, New York, N. Y. Formerly the residence of the late E. J. Berwind, it will be remodeled to provide for the libraries and exhibits of the institute.

New Aluminum Publication. *Aluminum Bulletin*, published by the Aluminum Association, New York, N. Y., made its first appearance under date of September 1945. This pamphlet will be published four times a year and will contain material having specialized rather than popular interest. The twofold purpose is to furnish a medium for reporting both to and from the aluminum industry, about the aluminum industry.

Future Meetings of Other Societies

American Society of Refrigerating Engineers. Forty-first annual meeting. December 10–12, 1945, New York, N. Y.

Institute of Aeronautical Sciences. Wright Brothers Lecture. December 17, 1945, Washington, D. C.

Institute of Radio Engineers. Winter technical meeting. January 23–26, 1946, New York, N. Y.

National Association of Corrosion Engineers. Annual meeting and convention. May 7–9, 1946, Kansas City, Mo.

RESEARCH

Science Controls Urged. A strong national policy for the promotion of science and democratic controls over its products to safeguard civilization was urged at the first seasonal meeting of the American Academy of Political and Social Science, October 5, 1945. Brigadier General David Sarnoff (M '23) president, Radio Corporation of America, declared that the United States must be first in science. He urged the exploration and development of every phase of technology and encouragement for every scientist for it is his belief that youth with an aptitude for science is the country's great national resource. "The Place of Science in a Democracy" was the theme developed by Waldemar Kaempffert, science editor of the *New York Times*, who asserted that it was inevitable that social inventions of fascism and communism would arise because social inventions had failed to keep pace with machine inventions. He declared that already the people are caught in a mechanized culture, and the mechanism of that culture is designed and controlled by the new caste that draws its power from science and technology.

Britain to Speed Research. With the objectives to maintain contact between British companies and research organizations and to encourage British industry to extend and utilize to the fullest its research facilities, Great Britain Federation of British Industries has voted to create a special research committee as liaison between industry and science. Sir William Larke will head the organization.

Technology in Postwar World. The United States "does not intend to play technological Santa Claus to the world" but, to retain its place in the world, technology must be added to the list of its exports. These sentiments were expressed by Maurice Holland (A '23, M '30) before the October 6, 1945, session of the Mexican-American Industrial Research Conference, sponsored by the Armour Research Foundation of the Illinois Institute of Technology, Chicago. He said that technology is the American passport to the postwar world and that in applying it to new industrial enterprises abroad the United States can draw upon its national resources of more than 100 government scientific and technical agencies; 2,500 industrial research laboratories; nearly 100 university and technical-college research centers; and 600 consulting, commercial, and testing laboratories operating in all major fields of industry.

Research Men Meet. More than 100 research directors and other industrial executives discussed common problems of research management at the fall meeting of the Industrial Research Institute, New York, N. Y., September 27–28, 1945. F. B. Jewett (HM '45) president, National Academy of Sciences, as one of the guest speakers, warned that industry must be careful not to jeopardize the future of research by draining colleges of their best teachers and scientific investigators. The group also visited the laboratories of the Radio Corporation of America, Princeton, N. J., where modern facilities for research were shown.

EDUCATION

War Developments Included in Brooklyn Curricula

The Polytechnic Institute of Brooklyn, Brooklyn, N. Y., has revised its electrical-engineering curriculum to include a series of courses based on the new war developments now released from government restriction. In announcing the new courses, Doctor Ernst Weber (F '34), head of the department of graduate study and research in electrical engineering, said that at the present time much of the equipment used in microwave research at the institute cannot be utilized for instructional purposes because it is under secrecy orders, but it is expected that the Government soon will release such orders on all basic scientific equipment developed in the field of microwaves during the war.

As a result of the major developments in the electrical-engineering field, the undergraduate course will have two options. The first will feature electric power and industrial applications and the second, electronics and communications. The first option will include, in addition to the usual work on electric machinery and power transmission, courses on industrial control and industrial electronics. The second option provides a revised curriculum to include the recent developments in ultrahigh frequencies in their application to frequency modulation and television. Both options of the undergraduate program include substantial laboratory work, and in the senior year embrace independent design projects in which the student learns to build up complete power or communications systems.

On the graduate level there is an extensive program in microwaves, generation, transmission, and reception in all phases, courses on servomechanism which proved useful during the war for gun direction of anti-aircraft, the theory of antennas and of television, and all types of modulation circuits.

New courses in electron optics covering the design of electron-focusing systems which produce images in television and other cases have been added to the graduate curriculum

Quarter System Replaces Semester. Because of Navy, Army, and war-training committments, reconversion of the curricula of the Georgia School of Technology, Atlanta, from a wartime to a peacetime basis will be made at the end of the 1945–46 academic year. The new peacetime plan will introduce the quarter system instead of the semester schedule. Under the new system there will be only one commencement each calendar year, and regular students will be granted bachelor-of-science degrees in engineering at the end of their fourth year upon successful completion of prescribed courses. Co-operative students, who spent part of their time in school and the other part in industry, will graduate at the end of five years. With the quarter system students with high scholarship standings will have an opportunity to finish a complete engineering course in three years by pursuing prescribed courses during the summer quarters.

Views Exchanged on Instrumentation. An educational conference "Instrumentation and the University," sponsored by the Carnegie Institute of Technology, Pittsburgh, Pa., and the Instrument Society of America, was held October 16 to 18, 1945, at the institute. The purpose was to provide an opportunity for an exchange of views among industrial-instrument users, Government agencies, instrument manufacturers, and the faculties in engineering and science. Among the speakers were H. B. Richmond (A '19, F '40) chairman of the board, General Radio Company, Cambridge, Mass.; A. F. Sperry (M '37) owner, Hubbard Engineering Company, Chicago, Ill.; and D. A. Young (A '35, M '41) manager, instrument section, meter division, engineering department, Westinghouse Electric Corporation, Newark, N. J. The chairman of the committee for the conference was B. R. Teare, Jr. (A '29, F '42), head of the electrical-engineering department, Carnegie Institute of Technology.

Curricula Changed at Columbus. Five-year curricula, replacing the present four-year programs in all degree-granting departments of the college of engineering, Ohio State University, Columbus, Ohio, became effective with the autumn period. The plan which will bring more of the so-called "cultural" courses into the engineering curricula was introduced with the new freshman class. Present students, returning students whose work was interrupted by the war or for other causes, and students transferring from other colleges will be permitted to choose between the four- and five-year curricula. This option will continue for the next two years.

Gas-Turbine Laboratory at MIT. Gifts totaling $500,000 for the establishment of a gas-turbine laboratory at the Massachusetts Institute of Technology, Cambridge, for graduate instruction and fundamental research have been announced by Doctor J. C. Hunsaker, head of the departments of aeronautical and mechanical engineering. Recent advances in gas-turbine design emphasize the need for specialized technical studies and the discovery of new techniques required in the construction of machines operating at extremely high speed, high temperature, and high compression. The institute's new laboratory, which is to be completed as soon as possible, will include a supersonic wind tunnel and facilities for research on the elements of compressors, combustion devices, jets, and gas turbines. Test facilities also will be provided for operation of such devices.

Gauge Laboratory in Atlanta. Re-establishment of the United States Army Ordnance Department gauge laboratory at the Georgia School of Technology, Atlanta, was announced jointly September 29, 1945, by Doctor B. R. Van Leer, president of the school, and Colonel J. E. Getzen, chief of the Birmingham ordnance district. The new installation, including equipment and air-conditioning facilities, is valued at approximately $150,000. This gauge laboratory was one of the first to be established in an institution outside of the National Bureau of Standards. Part of the equipment saw service in ordnance establishments in Louisiana and part was utilized in war industries in Birmingham.

Naval Trainees at Atlanta Limited. To accommodate the great number of war veterans and civilian students the increase in naval-trainee enrollment at the Georgia School of Technology, Atlanta, is being limited by available dormitory space to ten per cent, which means an increase from 639 to 749 men.

Night Courses in Engineering. The evening engineering program of Rutgers University, New Brunswick, N. J., was resumed on October 1, 1945, by the university extension division after a four-year cessation due to emphasis on war courses. Three-year college-level evening certificates will be offered in essentials of electrical engineering. These evening courses are designed primarily for part-time working students, war workers, and veterans who desire to continue their training.

Conferences on Distribution at Newark. A series of seven weekly conferences on "Engineering for Improved Distribution" has been inaugurated at Newark College of Engineering, Newark, N. J. Discussions will be carried on by two groups, one devoted to "Finding and Using Distribution Facts," and the other to "Promotion and Selling for Improved Distribution." Prominent sales engineers, promotion men, and advertising specialists have been selected as chairmen for the session. In addition to giving informal talks on broadly assigned topics, they will conduct round-table forums for the interchange of ideas. The conferences are endeavoring to co-ordinate production, research, sales, and distribution planning to meet the fullest impact of postwar reconversion.

Broader Training in Troy Curriculum. A postwar undergraduate curriculum developed in line with the scientific advances and social and economic changes coming out of World War II has been set up at Rensselaer Polytechnic Institute, Troy, N. Y. The chief aim, in addition to training students to become proficient engineers and scientists, is to help students understand their duties as intelligent citizens in an era of imposing wider responsibilities. Therefore, time allotted for the study of such subjects as economics, history, psychology, literature, and other nontechnical subjects is increased by a third. Study of mathematics, the sciences, and other fundamental subjects is increased, and specialization is modified in the belief that the college hours of the undergraduate can be spent more profitably in enlarging his comprehension of all the roots of engineering rather than narrowing down too much to those of a special field. All students can enter the third year with essentially a similar background in mathematics and sciences, and can begin in that year to choose options or electives providing emphasis on the special activity they wish to follow after graduation.

Jewett Fellowships Available. For the second year, applications for the Frank B. Jewett Fellowships for post-doctorate research in the physical sciences may now be obtained from the Frank B. Jewett fellowship committee, Bell Telephone Laboratories, 463 West Street, New York 14, N. Y. Applications for the current term are returnable to the committee by December 1, 1945, and awards will be announced February 1, 1946. These fellowships which include chemistry, mathematics, and physics, carry an award of $3,000 to the fellow and an honorarium of $1,500 to the academic institution where his research is pursued. The fellowships are open to both men and women who have obtained the doctorate or expect to receive it prior to the beginning of the fellowship term, which starts July 1, 1946, and ends 12 months later.

INDUSTRY • • • • •

Co-operation Between Government and Manufacturers Urged

Co-operation with the Government and a devotion of energies toward production, a policy which would lead to providing jobs, merchandise for thousands of hard-hit small retailers, and needed radio receivers for a consumer market, was urged by John Meck, president, John Meck Industries, Inc., Plymouth, Ind., who recently spoke before radio-trade-press representatives in New York, N. Y. He said that an attempt to force the hand of the Office of Price Administration by stalling production is contrary to the best interest of all.

The John Meck company, radio manufacturers, claims to be the first in the industry to produce a completely new postwar radio, an OPA-priced five-tube superheterodyne table model known as "The Trailblazer."

Cellulose in "Movies." The industrial film of the Hercules Powder Company, Wilmington, Del., "Careers for Cellulose," will be shown in 20 Latin American countries by the Office of Co-ordinator of Inter-American Affairs. The sound film, in color, now is being translated into Spanish and Portuguese. This behind-the-scenes story of one of America's newest and most colorful industries starts with the cotton fields, then shows the cotton being transformed into cellulose and other bases for plastics, lacquers, film, rayon, and other articles. The film follows the cellulose materials to testing laboratories and then demonstrates the possibilities of cellulose materials in a variety of industries.

Radiotelegraph Services Resumed. The reopening of direct radiotelegraph communications between the United States and Tokyo took place August 28 when the facilities of the Mackay Radio and Telegraph Company, a subsidiary of the American Cable and Radio Corporation, New York, N. Y., were placed in operation for the first time since Pearl Harbor. Radiotelegraph services over the Mackay circuit initially will be limited to official military and government, press, and prisoners-of-war messages. The operation of the Tokyo end of the circuit will be under the direction of the American Army of Occupation.

Steel Company Expands. To carry industrial science deeper into the service of postwar living, the Allegheny Ludlum Steel Corporation, Pittsburgh, Pa., will erect a $2,000,000 research laboratory and experimental center at its headquarters plant, Brackenridge, Pa.

JOINT ACTIVITIES

W. H. Harrison Elected 1945 Hoover Medalist

W. H. Harrison (A '20, F '31) recently elected vice-president in charge of operation and engineering, American Telephone and Telegraph Company, New York, N. Y., has been elected the eighth recipient of the Hoover Medal (1945). He held the abovementioned position prior to 1940 when he went on leave of absence to head the production division of the War Production Board. He left the latter organization in 1942 to become a brigadier general, United States Army. Later he was promoted to the rank of major general and made chief of the procurement and distribution service, Signal Corps. Upon his release he was awarded the Distinguished Service Medal in a personal presentation by General Brehon B. Somervell.

Mr. Harrison entered the Bell System in 1909 as a repairman for the New York Telephone Company. In 1915 he became engaged in circuit-design work with the Western Electric Company, New York, and joined the staff of the American Telephone and Telegraph Company in 1918. Later he served as equipment and building engineer and plant engineer.

The Hoover Medal was instituted by the late Conrad N. Lauer and its first presentation was made to Herbert Hoover (HM '29) in 1930. Other AIEE members who have been Hoover Medalists are: Gano Dunn (A '91, F '12), 1939, and Gerard Swope (A '99, F '22), 1942.

John Fritz Medal for 1946 Awarded to Zay Jeffries

The John Fritz Medal, "the highest award in engineering," will be given to Zay Jeffries (M '36, F '42) vice-president of the General Electric Company in charge of the chemical department at Pittsfield, Mass., for "leadership in the solution of problems affecting the production, conservation, substitution and the scientific appraisal of metals and alloys." A biographical sketch of him appears elsewhere in this issue.

The John Fritz Medal, established in 1902 by the national professional societies of civil, mining and metallurgical, mechanical, and electrical engineers, is given for notable scientific or industrial achievement, and is international in scope. The first award of the medal was made to John Fritz on his 80th birthday, and the medal for 1945 went to J. L. Savage.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the A.I.E.E. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Experience With a Heat-Pump System

To the Editor:

This letter further expands an article published in *Electrical Engineering* entitled "Experience With a Heat-Pump System" (*EE, Oct '44, p 361*).

The maximum theoretical coefficient of performance of a heat-pump system is given by the equation:

$$\text{Cop} = \frac{T_1}{T_1 - T_2}$$

in which:

T_1 = condenser temperature
T_2 = evaporator temperature

A simple substitution in this formula of the condenser and evaporator temperatures normally reached in operation will yield values which are several times greater than those actually obtained from the formula based upon energy ratio:

$$\text{Cop} = \frac{W_e + W_w}{W_e}$$

where

W_e = heat supplied from electricity
W_w = heat extracted from well water

This letter is an attempt to analyze qualitatively the various factors which cause this wide discrepancy between actual and ideal. The curve, Figure 1, is plotted with coefficient of performance against electric input to the system for the New Haven, Conn., office building of The United Illuminating Company.

Curve *A*, at unity coefficient of performance for all loads, represents any system of direct electric heating. Curve *F* is a plot of the ideal (Carnot cycle) ratios from the temperature equation mentioned earlier, substituting water temperatures leaving the condenser and evaporator for our specific conditions. Curve *B* shows the coefficient which actually was obtained in operation, as closely as can be determined from the data which have been available. This curve falls off at light loads because of the power required to run the auxiliaries, which is practically constant regardless of the load.

It is the difference between curves *B* and *F*, representing a substantial loss of availability, which is of interest to analyze. Curve *C* shows the coefficient of performance which would have been realized, if no auxiliary power had been required, or to state it differently, if the power consumed by the auxiliaries had been utilized at the same ratio as the power which went to the compressors. It should be noted that these curves do not represent actual energy and that the difference between curves *B* and *C* is not a loss of power. This energy is converted into usable heat but only on a one-to-one basis. The loss is essentially a loss of availability, because this energy fails to convert any low-grade heat from the well water.

Curve *D* carries the same principle one step further and shows the coefficient of performance which would have resulted had it not been necessary to supply power either to the auxiliaries or to make up the losses in the compressor motors. Again this represents a "loss of availability," because a portion of the input is utilized only on a direct one-to-one basis instead of being utilized to convert low-grade heat.

The next higher curve *E* shows the ratios which could have been developed by the hypothetical system of curve *D*, if the heat exchange in its condensers and evaporators had been 100 per cent efficient. Again no loss of energy is involved, but rather a loss of thermal head available, part of which has been required to transfer heat into the re-

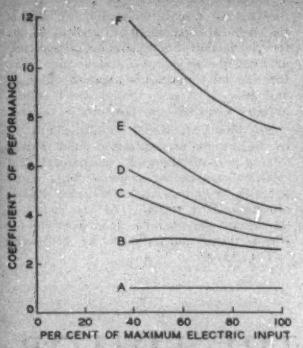


Figure 1. Coefficient of performance: theoretical–actual

A—For direct heating
B—Actual coefficient of performance for heat-pump system
C—With no auxiliary power
D—With no motor losses
E—With 100 per cent efficient heat transfer
F—Theoretical coefficient of performance for Carnot cycle

frigerant and back again. Curve *E*, therefore, represents the maximum coefficient of performance for the cycle. The difference between this line and curve *F* is accounted for by the interaction of all factors which cause the actual cycle to vary from the theoretical Carnot cycle.

Since the top curve represents the maximum possible ratios for a system operating between the temperature limits for this particular set of conditions, any improvement in operating economy must be accomplished by reducing the losses in availability which are shown here.

Of these losses, the first three can be analyzed and evaluated to determine how much gain could be expected. Motor losses are generally well understood, and it is doubtful whether any great improvement can be expected on this item. The other two are involved in a complicated economic balance between many factors. For example, consider the effect of changing the flow quantity of the heat-transfer medium, which in the case of the system described is water. To reduce this flow without any change in the size of equipment will decrease the auxiliary power requirements but increase the necessary temperature differentials. This would mean a reduction in the loss of availability represented by the space between curves *B* and *C* but an increase in that between curves *D* and *E*. To reduce auxiliary power without decreasing flow would require a larger investment in equipment and piping. Obviously, a careful analysis of such a complex interrelation would require a large fund of operating data, and the conclusions from such an analysis would not be necessarily typical of other systems. Although the data presented are neither sufficiently complete nor precise enough to permit a careful evaluation for this particular system, it is believed that the various factors are balanced approximately so that no major gain over the relations shown in Figure 1 could be economically justified.

Therefore, it would seem that any significant improvement over the performance which has been demonstrated by the system described must come from sources which are represented in the Figure 1 by the area between curves *E* and *F*. This is the field of the refrigeration engineer and concerns such technical considerations as compressor design and refrigerant properties.

E. HAVILAND WALTON
CHARLES A. WILLIAM (M '40)
(United Illuminating Company, New Haven, Conn.)

New Frequency Unit

To the Editor:

A need exists for a condensed scale of absolute frequency in cycles per second; and a similar need for frequency ratios. A scheme has been proposed recently based upon classification of frequency decades of electromagnetic wave radiation which includes the descriptive phrases "very low," "very high," and "super high" frequencies. Obviously such phrases are rather arbitrary and have no intrinsic mathematical significance; furthermore, attempts at extension of the scheme must inevitably lead to a terminology including such words as "mammoth" and "colossal."

Since the principal usefulness of a new frequency unit would be as a means of condensing the arithmetic scale, it is evident that a logarithmic scale should be adopted. This would follow the use of "bel" for power ratios in the communication literature, and "pH" for hydrogen ion concentration in the chemical literature.

It is proposed that a new logarithmic unit of frequency be adopted which could justly be called the "marconi" (after a worker who himself ranged over a great many frequencies), and defined as follows:

$$\text{marconi} = \log_{10} f \quad \text{(abbreviated "mi")}$$

in which f is in cycles per second. The ratio of two frequencies would similarly be defined and called the "marconi-ratio," thus

$$\text{marconi-ratio} = \log_{10} f / f_{\text{base}} \quad \text{(abbreviated "mir")}$$

in which f and f_{base} are the variable and base frequencies respectively.

The general adoption of the proposed frequency unit would give formal recognition to the common practice of utilizing logarithmic scales in graphs of frequency functions. The unit would be useful whenever utilizing phenomena defined in terms of "cycles per second," for it could replace such expressions as "a period of 10 seconds" by "−1.0 marconis"; and such cumbersome numbers as "10,000,000 kilocycles per second" by "10 marconis."

P. M. HONNELL
(Lieutenant Colonel, Signal Corps, Department of Chemistry and Electricity, United States Military Academy, West Point, N. Y.)

NEW BOOKS

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Sampling Statistics and Applications. (Fundamentals of the Theory of Statistics.) By J. G. Smith and A. J. Duncan. McGraw-Hill Book Company, New York, N. Y., and London, England, 1945. 498 pages, diagrams, charts, tables, 8 1/2 by 5 1/4 inches, cloth, $4. (ESL.)

After reviewing basic concepts and definitions, the authors discuss the general theory of frequency curves and the theory of random sampling. Important sampling distributions are derived, and their applications to a variety of problems are illustrated. Both exact and approximate sampling methods are considered with their proper fields of use. The character of assumptions involved in theory is treated explicitly, and the problems that such assumptions present in practical applications are illustrated.

(The) **Simple Calculation of Electrical Transients.** By G. W. Carter. University Press, Cambridge, England; Macmillan Company, New York, N. Y., 1945. 120 pages, diagrams, tables, 8 1/4 by 5 1/4 inches, cloth, $1.75. (ESL.)

This small volume provides an elementary treatment of transient problems by Heaviside's operational method in linear electrical circuits with lumped elements. The emphasis is on the physical or engineering side, and many worked examples are given, based on real engineering or laboratory problems. The basic algebra and calculus necessary for a proper understanding of the book have been included in appendixes for those who need the information.

PAMPHLETS

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers

Cellulose Acetate—Properties and Uses. (Revised edition.) Hercules Powder Company, Wilmington, Del., unpaged.

Elements of Speech Input Systems (Studio Applications), Western Electric Company, New York, N. Y., 17 pages.

Permanent Magnets for Industry. The Arnold Engineering Company, Chicago 11, Ill., 24 pages.

The Physically Impaired—A Guidebook to Their Employment. Association of Casualty and Surety Executives, New York 7, N. Y., 36 pages.

Patents and Your Tomorrow. National Association of Manufacturers of the United States, New York 20, N. Y., 22 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Judging Mica Quality Electrically

K. G. COUTLEE
NONMEMBER AIEE

MICA CAPACITORS by the millions have been used in radio, radar, and other important electronic equipment for our Armed Forces. The unprecedented demand has strained all our resources, and much time and money have been spent in efforts to solve the mica supply problem. One of these was a research project conducted by Bell Telephone Laboratories for the War Production Board. It was concerned with the development of electrical test methods to predetermine the quality of raw mica in terms of end-use requirements in various grades of capacitors. After over two years of work covering development, design, laboratory trial and an extensive commercial trial of two types of test instruments, this project has been brought to a successful conclusion. As the electrical method of classification makes possible the use of mica available in large quantities, but previously considered unsuitable for capacitors, the mica supply for capacitors is greatly increased. An estimated saving up to 60 per cent of the total amount of higher-quality mica used in capacitors is indicated.

Mica possesses many useful properties that make it particularly attractive as a capacitor dielectric. In general, these are high dielectric strength, high dielectric constant, low dielectric loss, chemical inertness, low-temperature coefficient of expansion, and good resistance to heat. The important feature that makes it possible to utilize these properties in a capacitor is that mica can be readily split into very thin films of uniform thickness.

India is the chief source of supply of capacitor mica due to its extensive resources of high-quality mica, low labor cost, and a long established business in supplying world-wide markets. Other less developed sources are South America, the United States, and Canada. With the advent of war, the sharp increase in demand for mica, coupled with wartime shipping hazards, created a scarcity. The Government immediately took steps to insure that the supply from established sources would be increased, to find new sources, and to encourage the development and use of mica substitutes.¶

Paper 45-155, recommended by the AIEE committee on communication for publication in AIEE TRANSACTIONS. Manuscript submitted June 5, 1945; made available for printing August 1, 1945.

K. G. COUTLEE is with the Bell Telephone Laboratories, Inc., New York, N. Y.

This work was carried out by the Bell Telephone Laboratories, Inc., under a contract between Western Electric Company and the War Production Board under the supervision of the National Academy of Sciences. The capacitor manufacturers that participated in the tests were Aerovox, Cornell-Dubilier, Electro Motive Manufacturing, Micamold, Sangamo, Solar, Sprague, and Western Electric Companies. The various types of mica used in the tests were chosen by the mica-graphite division of the War Production Board and furnished by Colonial Mica Corporation as agent of Metals Reserve Corporation. This project was carried out under difficult wartime conditions, and particular credit is due the capacitor manufacturers for their patience and skill in steering the test lots through the shop without losing track of their identity. Through their efforts, it is believed that a valuable contribution has been made to the capacitor art. It has afforded an opportunity to observe, by actual tests, the effects of various defects in mica that generally have been considered undesirable for capacitor use.

Visual Quality Classification of Mica

The Indian visual system of classifying natural ruby mica incorporated in American Society for Testing Materials method *D*351 lists seven different qualities (see Table I). It had become more or less standard practice with capacitor manufacturers to consider all qualities below fourth quality (ruby good stained) as unsuitable for capacitor use, and a great many preferred not to go beyond third-best quality (ruby fair stained). Under no conditions was mica used that contained black spots or stains. Capacitor manufacturers had found from experience that by employing these better qualities of ruby muscovite mica a satisfactory product would be obtained. Unfortunately, the better qualities constitute a relatively small portion of total mica production, and the expected wartime demand far exceeded the supply. There was no satisfactory evidence however, that some and perhaps much of the lower-quality ruby and other types of mica might not also have been suitable for capacitor use.

Table I. India* Visual System for Classifying Quality of Natural Mica

Clear
Clear and slightly stained
Fair stained
Good stained
Stained
Heavy stained
Black stained and spotted

*See reference 1.

More Positive Test Needed

The War Production Board sought the assistance of Bell Telephone Laboratories in the fall of 1942 to devise electrical test methods that could be used to select mica for capacitor use. Such tests, or methods of classification, while assuring that no defective mica could be put into finished capacitors, were also to insure that no good mica of any type was rejected. The problem was not only to select mica from new sources where appearance was a questionable guide, but, of perhaps even greater importance, to salvage satisfactory capacitor mica from the large available stocks of mica which had been rejected as unsuitable for capacitors by visual standards.

Mica-Capacitor Requirements

Generally speaking, mica capacitors for military equipment can be divided into two broad groups in respect to duty required. The first group comprises those

Table II. Q and Power-Factor Values for Electrical Quality Groups, *E*-1, *E*-2, and *E*-3

Q or Power-Factor Group	Form	Q Value	Power Factor	Rapid-Method Meter Reading: 0.010 In.† (0.007 to 0.015 In.)	0.020 In.† (0.015 to 0.025 In.)	0.030 In.† (0.25 to 0.035 In.)
E-1	Block mica	2,500 minimum	0.0004 maximum	95 to 100	95 to 100	95 to 100
	Films*	2,500 minimum	0.0004 maximum			
E-2	Block mica	350 to 2,500	0.00285 to 0.0004	87 to 95	77 to 95	71 to 95
	Films*	1,500 minimum	0.00066 maximum			
E-3	Block mica	50 to 350	0.02 to 0.00285	50 to 87	32 to 77	24 to 71
	Films*	200 to 1,500	0.005 to 0.00066			

*Probable *Q* values of molded-type 1,000-micromicrofarad (American War Standard *C*75.3) stacked-foil and silvered capacitors. These will apply when all factors that would adversely influence the *Q* value are under control.

†Thickness of block mica or mica films stacked to this thickness.

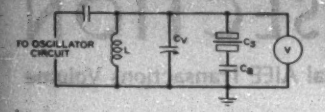


Figure 1 (left). Simplified circuit indicating the method of testing for Q or power factor

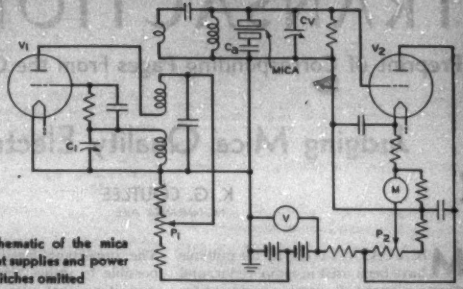


Figure 2. Circuit schematic of the mica Q test set with filament supplies and power and voltage switches omitted

used principally in high-stability tuned circuits, some of which must carry appreciable amounts of radio-frequency current. The second group embraces those used in less critical circuits for coupling, blocking, and by-pass purposes. Of equal importance to both groups is dielectric strength and long life; hence, all capacitor mica must be free of cracks, tears, pinholes and conducting foreign inclusions, which might adversely influence such properties. Mica for the first group must have low dielectric loss, and its characteristics must be such that wide temperature changes will cause only minor capacitance changes, and these always must repeat themselves. It is also preferable that mica be free of excessive waviness and air inclusions.

In the case of capacitors in the second group, the requirements are such that they can be met easily even with low-quality mica; a number of other materials, such as oil-impregnated paper, resin-treated paper, and resin-treated clay, also proved suitable. There also are certain other materials such as fused silica, titanium-dioxide mixtures, steatite, and glass, with characteristics that permit their use in some capacitors of the first group. However, the inferiority to mica in either dielectric strength or dielectric constant generally limited their use to smaller capacitance types.

Mica Properties Needing Control

As the dielectric constant of mica was found to show relatively little variation for different types and qualities from world-wide sources, no control of this property seemed necessary. Efforts were directed accordingly toward developing suitable test methods to determine the other important electrical properties of mica for capacitors: namely, dielectric loss and dielectric strength. As it seemed considerable testing might be carried out at mine locations, standard[7] power-factor methods for mica obviously were too cumbersome and slow. The ideal would be a rapid power-factor test method in a portable test-set form. Several methods were tried, and finally one was found that appeared suitable for quickly classifying the power factor of raw "block" mica (0.007 to 0.030 inch thick) as it appears in commerce.

Rapid Power-Factor Test Method

This method gives a reliable numerical indication of power factor or its approximate reciprocal equivalent Q as a single reading of a meter. Essentially it comprises a resonant circuit in conjunction with adjustable two-inch circular flat test electrodes mounted in a heavy metal frame. The choice of two-inch electrodes was based on the optimum size of block mica used for capacitors, and permitted the testing of mica somewhat smaller than the electrodes up to five inches in width. Forming an integral part of the moving upper electrode and connected to the grounded side of the test circuit is a fixed air capacitor of 20 micromicrofarads (20×10^{-12} farads). A schematic of the test circuit is shown in Figure 1, and in diagrammatic form in Figure 2. A vacuum-tube oscillator is capacitively coupled and tuned to the test circuit. Resonance is indicated by a vacuum-tube voltmeter connected in parallel with the tuned circuit. The inductive portion of the tuned circuit is a coil having a Q of approximately 300 at one megacycle. A test frequency of one megacycle was used at the request of the War Production Board, as the greatest number of capacitors were operating in the radio-frequency range. During initial adjustment, the test electrodes are closed, which connects the 20-micromicrofarads fixed capacitor in parallel with the coil. Oscillator input and tuning adjustments are made to bring the reading of the voltmeter to full-scale deflection. The electrodes then are opened by turning the knob that raises the upper fixed-capacitor electrode, and a test sample is clamped between electrodes. Only one adjustment is necessary to re-establish resonance. This is accomplished by adding to the circuit the small amount of capacitance that is lost when the relatively high-capacitance block-mica sample (150 to 450 micromicrofarads) is placed in series with the 20-micromicrofarad fixed capacitor. This additional capacitance is furnished by a 10-micro-

Table III. Electrical, Physical, and Visual Quality Requirements of Natural Block Mica and Mica Films for Use in Capacitors

	Class C-1	Class C-2	Class C-3
Electrical Properties			
Conductivity	None	None	None
Q value or power factor at 1 megacycle	E-1	E-2	E-3
Dielectric strength, volts per mil at 60 cycles per second (average)	1,000	1,000	1,000
Dielectric strength, volts per mil at 60 cycles per second (single)	850	850	850
Dielectric constant	*	*	*
Physical Properties			
Weight loss on heating (5 min at 600 C), maximum, per cent	0.2	0.2	
Thickness uniformity (mica films)	Best	Best	Intermediate
Temperature coefficient of capacitance and retrace	†	†	†
Visual Qualities			
Air inclusions A	None to slight	None to slight	None to slight
Air inclusions B	Medium	Medium	Medium
Air inclusions C	Medium to heavy	Medium to heavy	Medium to heavy
Waves A	Flat to slight	Flat to slight	Flat to slight
Waves B	Medium	Medium	Medium
Waves C	Medium to heavy	Medium to heavy	Medium to heavy
Cracks	None	None	None
Tears	None	None	None
Pinholes	None	None	None
Stones	None	None	None
Buckles	None	None	None
Ridges	None	None	None

*As the dielectric constant of natural block mica suitable for use in capacitors is fairly uniform, no specified requirement is needed.

†It has been found that the temperature coefficient of capacitance and retrace of capacitors made with classes C-1, C-2, and C-3 mica are more dependent on such factors as electrical and mechanical design and manufacturing technique than any differences that may be attributed to the mica itself.

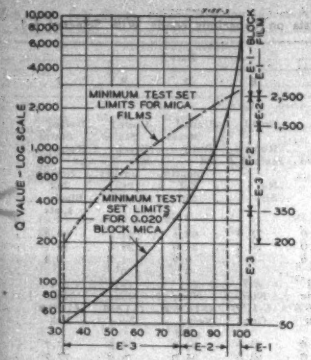


Figure 3 (left). Typical calibration curves for mica Q test set

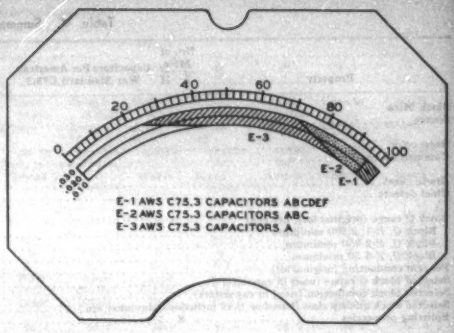


Figure 4 (right). Meter scale of the mica Q test set

microfarad vernier capacitor connected in parallel with the coil.

In following such a procedure the initial frequency of the circuit is duplicated each time a sample is tested. In other words, once the initial setting is made, all that is necessary to make a series of tests is to clamp the test specimen between the electrodes each time, make one simple adjustment of the vernier capacitor to obtain maximum deflection of the meter and read the meter scale corresponding to the thickness of the specimen as indicated by a scale on the clamping dial. It was possible to test up to 15 samples per minute, compared with about 15 minutes per sample.

If the Q of the test specimen of mica is of the order of 10,000 (power factor 0.0001), the needle of the meter will return to the initial full-scale deflection. If the Q is lower, the meter will read less than full scale, depending upon its magnitude.

The Q of block mica of any basic color or visual quality (based on minimum values) is shown in terms of rapid method Q test-set readings in Figure 3. The minimum equivalent Q of films split from such block mica (in the form of molded silver-electrode 1,000-micromicrofarad capacitors) also is plotted in terms of Q test-set readings originally obtained for the block. These data indicate that the Q at one megacycle of films (in capacitors) split from high Q block may not attain so high a value as the block. Probable reasons for this are dielectric loss in the molded capacitor housing, impregnants and moisture residuals, as well as series resistance in leads and electrodes. In the case of films split from low Q block such films most always show a higher Q at one megacycle than the block. Generally, this is believed to be due to the release of moisture during splitting, since the Q reading of a bundle of splits usually is higher than that of the block. However, in some cases this apparently is not so, and no improvement in Q is accomplished, even after baking at temperatures as high as 1,000 degrees Fahrenheit. Such behavior does not seem to be specifically confined to any particular type of mica or to any peculiar variety of foreign inclusions. Persistently low Q mica may be:

1. Clear with no visible foreign inclusions.
2. Clear with numerous small air inclusions.
3. Clear with minute black specks in the form of a gray cloudy haze.
4. Black spotted and stained mica.

It seems evident, based on Q-frequency behavior, wherein the Q drops to abnormally low values at low frequency, that such low Q as cases 1 and 2 is due to entrapped moisture that is not readily released. In cases 3 and 4 low Q apparently arises from dielectric loss in the spots and stains.

In setting limits for Q, it appeared reasonable to establish three ranges based on Q actually obtainable with mica rather than on Q requirements imposed by circuits. The upper range would cover the highest Q obtainable for any block mica, the middle range a very high order of Q but somewhat less than the best obtain-

Table IV. Experimental Laboratory Trial of Mica Test Sets

		Block					Capacitors Made With Films From Electrical Selected Block						
				Electrical Quality									Aging¶
Lot	Source	Visual Quality	Color	Conducting Inclusions	1 Mc Q Range	Meter Reading	Average† Q (1 Mc)	Dielectric Strength‡ (Per Cent Correct)	Insulation Resistance‡ (Per Cent Correct)	Corona Voltage§ (Volts 60 Cps)	Life Test§ (Tested)	Life Test§ (Failed)	(Per Cent Change in Capacitance)
India	India	Fair stained	Ruby	No	E-1	99	5,000	100	100	244 average	8	0	0.077 average
A	S. D.	Clear	Ruby	No	E-1	99	3,900	100	100	269 average			0.195 average
A	S. D.	Stained	Ruby	No	E-2	93	3,100	100	100	253 average	6	2	0.211 average
B	N. C.	Clear	Ruby	No	E-1	99	4,900	100	100	270 average			0.100 average
B	N. C.	Stained	Ruby	No	E-2	94	3,800	100	100	261 average	6	1	0.177 average
C	N. M.	Clear	Green	No	E-2	93	2,800	100	100	256 average			0.077 average
C	N. M.	Stained	Green	Yes	Below E-3	*	140	100	100	268 average	6	0	0.319 average
D	N. C.	Clear	Green	No	E-1	96	3,500	100	100	265 average			0.212 average
D	N. C.	Stained	Green	No	E-2	93	2,800	100	100	243 average	6	0	0.161 average
E	N. H.	Clear	Ruby	No	E-1	97	4,100	100	100	266 average			0.260 average
E	N. H.	Stained	Ruby	No	E-1	96	3,800	100	100	245 average	6	0	0.169 average
F	Conn.	Clear	Ruby	No	E-2	93	3,500	100	100	260 average			0.216 average
F	Conn.	Stained	Ruby	No	E-2	89	2,400	100	100	246 average	6	0	0.264 average
G	N. C.	Stained	Green	Yes	E-2	80	1,700	100	100		4	0	

* Satisfactory readings could not be obtained in most cases.

† 1,000-micromicrofarad silver-molded capacitors.

‡ 1,000-micromicrofarad silver and 4,000-micromicrofarad foil-molded capacitors.

§ 4,000-micromicrofarad foil-molded capacitors.

¶ 5 cycles, +72 F to −40 F to +72 F to +185 F, 1,000-micromicrofarad silver-molded capacitors.

Table V. Summary of Manufacturers' Data on Capacitors Made With Selected *E*-1,

Property	No. of Mfrs. I	No. of Mfrs. II	Capacitors Per American War Standard C75.3		Part I A	Part I B	Part I D	Part I E	Part I F
Block Mica									
Source					India	Brazil	United States	United States	United States
Basic color					Ruby	Ruby	Ruby	Green	Ruby
Commercial quality					Stained	Stained *B*	2d quality	2d quality	2d quality
Grade (size)					No. 4	No. 4	2x2	2x3	2x2
Chief defects					*Air	Air	Air		Black spots
Block *Q* range (original lot), per cent									
Block *Q*, *E*-1, 2,500 minimum					94.0	77.0	68.1	64.3	80.5
Block *Q*, *E*-2 350 minimum					6.0	20.6	31.0	34.5	19.1
Block *Q*, *E*-3 50 minimum					0.0	2.4	0.9	1.2	0.4
Per cent conducting (original lot)					0	0	0	0	5
Selected block *Q* range (used in capacitors)					*E*-1	*E*-1	*E*-1	*E*-1	*E*-1
Selected block conduction (used in capacitors)					None	None	None	None	None
Selected block quality class (based on *Q* air inclusions, waviness, etc.)					*C-1 *B B*	*C-1 *C B*	*C-1 *C+ *B*	*C-1 *A B*	*C-1 *B B*
Splitting properties		8	2		Fair	Good	Very good	Good	Fair
Films, 1 to 4 mils (per cent yield)		9	2	Average	75.0	93.0	94.0	90.5	87.7
				Minimum	75.0	93.0	94.0	79.0	77.7
Laminations (per cent yield)		7	2	Average	35.5	37.1	34.8	39.3	35.4
				Minimum	22.8	28.9	27.3	31.2	21.3
Silvered laminations (per cent yield)		5	1	Average	89.9	86.8	81.7	90.3	88.5
				Minimum	82.5	82.0	70.7	84.6	79.3
Capacitors									
Capacitor *Q* (statistical distribution)	5	1	*CM30*—1,000-*µµf*, silver	Per cent >2,500	98.8	93.7	90.1	97.1	99.1
				Per cent 1,500–2,500	1.1	5.7	9.0	2.8	0.9
				Per cent 200–1,500	0.1	0.6	3.7	0.1	0.0
	6		*CM30*—1,000-*µµf*, foil	Per cent >2,500	94.5	95.6	97.2	94.7	96.8
				Per cent 1,500–2,500	5.4	4.1	2.4	5.2	2.2
				Per cent 200–1,500	0.1	0.3	0.4	0.1	1.0
	3	1	*CM55*—1,000-*µµf*, foil	Per cent >2,500	99.8	95.0	96.6	99.1	98.8
				Per cent 1,500–2,500	0.2	2.7	2.1	0.7	1.0
				Per cent 200–1,500	0.0	2.3	1.3	0.2	0.2
	3	1	*CM70*—510-*µµf*, foil	Per cent >2,500	76.5	87.0	51.3	86.0	78.1
				Per cent 1,500–2,500	18.5	13.0	44.2	7.0	21.9
				Per cent 200–1,500	5.0	0.0	4.5	7.0	0.0
American War Standard dielectric strength (per cent meeting requirement)	7	1	*CM30*—1,000-*µµf*, silver		95.5	98.1	98.7	97.0	96.7
	8		*CM30*—1,000-*µµf*, foil		95.5	95.6	96.8	96.6	96.7
	3	1	*CM55*—1,000-*µµf*, foil		95.9	98.2	95.8	96.5	96.1
	2	1	*CM35*—6,200-*µµf*, foil		92.2	94.8	99.3	96.8	99.7
	2	1	*CM60*—6,200-*µµf*, foil		96.1	99.5	98.9	93.2	91.0
	4	1	*CM70*—510-*µµf*, foil		100.0	100.0	100.0	100.0	100.0
American War Standard insulation resistance (per cent meeting requirement)	7	1	*CM30*—1,000-*µµf*, silver		99.9	99.6	99.7	99.5	99.6
	8		*CM30*—1,000-*µµf*, foil		99.8	99.1	99.3	99.8	99.4
	3	1	*CM55*—1,000-*µµf*, foil		99.7	99.7	99.9	99.9	99.9
	2	1	*CM35*—6,200-*µµf*, foil		98.4	99.2	99.2	96.0	99.3
	2	1	*CM60*—6,200-*µµf*, foil		100.0	100.0	100.0	100.0	100.0
	4	1	*CM70*—510-*µµf*, foil		100.0	100.0	100.0	100.0	100.0
American War Standard radio-frequency heating (per cent meeting requirement)	4	1	*CM70*—510-*µµf*, foil		100.0	100.0	100.0	100.0	100.0
Corona starting voltage—60 cycles per second—(no American War Standard requirement)	1		*CM70*—510-*µµf*, foil	(5 sections)	1,900	2,200	2,700	2,300	2,000
	1		*CM70*—510-*µµf*, foil	(8 sections)	3,600	3,500	3,600	3,600	3,400
	1		*CM70*—510-*µµf*, foil	(9 sections)	4,300	4,100	4,000	4,000	4,600
American War Standard temperature—coefficient and drift (American War Standard characteristic)					†1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
	5	1	*CM30*—1,000-*µµf*, silver		*E D B*	*D C B*	*D C B*	*E D B*	*E D C*
	6		*CM30*—1,000-*µµf*, foil		*C B B*	*B B B*	*B B B*	*B B B*	*C B B*
	3		*CM55*—1,000-*µµf*, foil		*B B B*	*B B B*	*B B B*	*C B B*	*C B B*
	2	1	*CM70*—510-*µµf*, foil		*D D D*	*D D D*	*D C B*	*D D C*	*D D D*
‡ American War Standard capacitor life (per cent meeting requirement)	5	1	*CM30*—1,000-*µµf*, silver		93.7	100.0	100.0	97.9	100.0
	5		*CM30*—1,000-*µµf*, foil		100.0	100.0	98.2	98.2	100.0
	3	1	*CM55*—1,000-*µµf*, foil		100.0	92.7	100.0	100.0	98.3
	2	1	*CM35*—6,200-*µµf*, foil		100.0	96.0	96.0	100.0	100.0
	1	1	*CM60*—6,200-*µµf*, foil		92.0	88.0	96.0	96.0	96.0
	3	1	*CM70*—510-*µµf*, foil		100.0	100.0	100.0	100.0	100.0
Grand Averages									
American War Standard dielectric strength (per cent meeting requirement)			All types and sizes of above capacitors		95.8	97.7	98.2	96.6	96.7
American War Standard capacitor life (per cent meeting requirement)			All types and sizes of above capacitors		97.6	96.1	98.4	98.7	99.1

able, and a third range of somewhat lower order of *Q*, but high as compared with other types of insulating materials in general. The top *Q* range simulated that normally assumed for mica and presumably used in capacitors in the past. While it became evident that such high *Q* actually is only needed in a relatively small percentage of capacitors, of the previously mentioned first group, it affords a margin of safety to which capacitor manufacturers apparently are accustomed. The middle range probably is high enough for all but the most critical types of capacitors of the first group, and the third *Q* range is suitable for by-pass, blocking, and coupling types of capacitors of the second group. These three ranges are designated *E*-1, *E*-2, and *E*-3, respectively, and the minimum *Q* limits assigned to each range are shown in Table II as well as equivalent test-set readings. This table also shows minimum *Q* limits for mica films split from the block. The actual calibration of the scale of the meter is shown in Figure 4.

Spark-Test Set

It was observed in studies of various types of block mica that the *Q* of "black stained and spotted" samples, in some cases, was just as high as that observed

E-2, and E-3 Block Mica Showing Over-All Performance From Block to Capacitor

Part I (Continued)					Part II								
H	I	J	L	M	N-1	N-2	N-3	N-4	N-5	O	P	Q	R
United States Ruby 2d quality 2x3 Waves	United States Green 2d quality 2x2 Black spots	United States Ruby 2d quality 2x3 Waves	Canada Green 2d quality 2x3	India Ruby Good stained No. 4 Air	United States Ruby 3d quality Black spots	United States Ruby 3d quality Reeves	United States Ruby 3d qualify Smoke	United States Ruby 3d quality Clay	United States Ruby 3d quality Waves	United States Green 3d quality 2x3 Black spots	United States Green 3d quality 2x3 Reeves	Canada Green 2d quality 2x3 Smoke	Canada Green 3d quality 2x3 Spots
79.0	67.8	91.2	45.6	96.6						35.0	92.0	41.5	18.1
20.5	27.7	8.4	34.8	3.1						42.0	8.0	30.8	18.0
0.5	3.6	0.4	19.6	0.3						23.0	0.0	27.7	63.9
0	5	0	0	0	0	0	0	0	0	0	0	0	50
E-1 None C-1BC Good	E-1 None C-1BC Fair	E-1 None C-1AB Good	E-1 None C-1AA Good	E-1 None C-1BB Very good	E-1 None C-1AB Very good	E-1 None C-1BC Poor	E-1 None C-1BB Good	E-1 None C-1BB Good	E-1 None C-1BC Poor	E-1 None C-1BB Fair	E-1 None C-1BC+ Poor	E-1 None C-2AB Good	E-3 Slight C-3AB Good
87.9	90.4	90.8	90.3	93.7	95.2	90.9	95.4	93.7	94.0	83.4	66.0	84.3	83.4
78.0	83.0	82.0	86.0	92.0									
36.8	35.7	35.7	38.6	38.5	42.3	42.6	41.6	43.4	43.1	34.2	26.8	36.1	38.6
23.5	22.6	27.0	28.2	21.8									
82.9	87.5	85.3	90.0	85.3						97.2	91.1	90.2	86.6
68.2	80.6	69.3	81.6	75.8									
99.5	94.9	98.8	95.0	98.2						87.1	98.5	79.2	16.2
0.3	4.7	1.1	3.0	1.4						11.6	1.5	17.9	37.3
0.2	0.4	0.1	2.0	0.4						1.3	0.0	2.9	46.5
95.3	92.1	97.9	92.0	96.2									
4.0	5.6	2.0	4.5	3.7									
0.7	2.3	0.1	3.5	0.1									
99.0	92.8	99.7	96.0	98.6						91.7	98.0	59.0	3.4
0.8	6.1	0.3	1.2	1.0						6.7	0.5	20.0	13.6
0.2	1.1	0.0	2.9	0.4						1.6	1.5	21.0	83.0
95.2	82.0	89.3	46.1	91.9	100.0	80.0	90.0	100.0	100.0				
4.8	10.2	8.3	47.7	8.1	0.0	10.0	10.0	0.0	0.0				
0.0	7.8	2.4	6.2	0.0	0.0	10.0	0.0	0.0	0.0				
97.7	96.1	96.7	97.9	99.0						95.9	98.8	98.8	98.3
96.6	95.2	97.5	97.4	96.3									
94.4	93.5	97.9	98.6	98.5						92.3	98.7	98.1	95.1
95.7	99.2	96.2	94.0	97.7						86.9	99.2	97.7	95.7
93.7	94.0	99.1	97.9	96.1						89.4	79.1	95.5	93.1
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0				
99.9	99.5	99.4	98.4	99.7						100.0	100.0	100.0	100.0
99.6	99.8	99.7	99.8	99.7									
98.9	99.9	99.8	99.7	98.1						100.0	100.0	100.0	100.0
99.6	96.1	100.0	99.6	97.7						100.0	100.0	100.0	100.0
100.0	100.0	100.0	100.0	100.0						100.0	100.0	100.0	100.0
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0				
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0				
2,000	2,500	1,900	1,900	2,400									
3,500	3,800	3,500	3,800	3,600									
3,900	4,200	4,200	3,400	4,100									
1 2 3 E D C C B B B D D D	1 2 3 D C B E D B C B B C B B D C B	1 2 3 E D B C B B B D D D	1 2 3 E D B E D C C B B C B B E D C	1 2 3 E D C C B B B D D D	1 2 3 D — B	1 2 3 E — D	1 2 3 E — B	1 2 3 D — B	1 2 3 D — B	1 2 3 F — D	1 2 3 F — D	1 2 3 F — D	1 2 3 F — D
100.0	97.9	100.0	100.0	100.0						100.0	100.0	100.0	100.0
100.0	96.0	100.0	100.0	98.2									
98.0	95.5	100.0	96.9	97.9						100.0	100.0	100.0	100.0
91.0	91.0	96.0	91.0	100.0						100.0	100.0	100.0	92.0
92.0	96.0	96.0	88.0	96.0						96.0	91.0	92.0	75.0
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0				
96.3	96.3	97.9	97.6	97.9	100.0	100.0	100.0	100.0	100.0	91.1	93.9	97.5	95.5
96.8	96.2	98.7	96.0	98.7	100.0	100.0	100.0	100.0	100.0	90.0	97.7	98.0	91.7

* Quality designation per ASTM 748. † 1 = average-averages. 2 = average-minimums. 3 = minimums.

‡ Excluding breakdowns due to causes other than mica puncture.

for any of the samples including the clear ones, whereas other "black stained and spotted" samples had very low Q values. It was found that low Q in "black stained and spotted" samples usually occurred when the stains were semiconducting in nature. Such conductivity, when present, could be detected by a high-voltage spark furnished by a vibrator-type induction coil, connected to a probe electrode, when the probe was used to explore the surface of the mica. Conducting spots and stains are revealed by sparkling and glowing at or near the probe but not by puncture by the spark. Mechanical faults, such as pinholes, tears, and cracks also can be located with this test; such defects are revealed by puncture of the mica by the spark. A schematic of this test circuit is shown in Figure 5.

Laboratory Trial of Test Sets

First, an experimental laboratory trial of the two types of test instruments was conducted in which "clear" to "black stained and spotted," green and ruby block mica from seven domestic mines was classified for Q at one megacycle with the rapid-method Q test set and tested for conducting inclusions with the spark test

set. This electrically selected block was split and punched into capacitor laminations 1.2 to 1.6 mils thick using standard commercial methods. These laminations were used indiscriminately, regardless of any visual inclusions and only were discarded if found to be mechanically unsound. Both 1,000-micromicrofarad and 4,000-micromicrofarad molded-silvered and foil "postage-stamp"-type capacitors were made by the Western Electric Company with this mica.

Thorough performance tests were made on these capacitors, and they satisfactorily met Q, insulation-resistance, dielectric-strength, corona-voltage and life requirements (see Table IV). As a result of these tests, it was concluded that block mica could be selected dependably for use in capacitors, some for the better grades and the rest for less critical types, and that the test methods appeared entirely adequate for the electric control of capacitor mica. Even the two lots of capacitors made with block mica in which conducting inclusions were detected by the spark test and low Q by the block-mica Q test gave excellent dielectric strength and life performance. It therefore appeared evident that such mica of *E*-2 and *E*-3 electrical quality might be used for less critical grades of capacitors with better over-all characteristics than can be obtained with some of the available alternate materials. However, as a precautionary measure, the use of mica with conducting inclusions was ruled out, in view of the apparent plentiful supply of types not possessing this defect.

Over-All Quality Specification

A specification[9] was developed containing over-all requirements for block mica for use in capacitors incorporating the two electrical test methods as well as other electrical, visual, and physical requirements. The electrical requirements covered Q, dielectric strength, and absence of conducting inclusions. The physical requirements covered splitting quality and weight loss on heating. Visual requirements covered air inclusions, waves, buckles, ridges, cracks, tears, pinholes, and stains. Three quality classes were set up for block mica suitable for use in capacitors, designated *C*-1, *C*-2, and *C*-3.

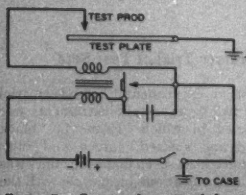


Figure 5. Circuit schematic of the spark-test set

Class *C*-1 is considered adequate for any and all of the various grades of capacitors in American War Standard *C*75.3. Classes *C*-2 and *C*-3 are considered usable for the less exacting grades. *C* classifications cover both electrical and physical properties and *E* classifications electrical properties only. Class *C*-1 covers *E*-1 mica with best electrical and physical properties, *C*-2 covers *E*-2 mica with intermediate electrical and physical properties and *C*-3 covers *E*-3 mica with fair electrical and physical properties. The stipulation is made, however, that mica shall meet all requirements of its respective class.

Commercial Trial of Test Sets

The next step was to try out the proposed system on a commercial scale, using the testing equipment that had been developed. A commercial design of the block-mica Q test set which is portable and contains its own batteries is shown in Figure 5. The spark-coil conductivity test set, which also is battery-operated and portable, is shown in Figure 6.

The commercial trial covered the electrical classification of over 3,000 pounds of block mica of 22 different types from the United States, India, Canada, and Brazil, previously classified by visual standards as stained, stained *B*, United States second and United States third quality. All such classifications were previously considered unsuitable for capacitor use. After being split, gauged, and punched, this mica was used, regardless of visible inclusions, providing it did not contain cuts, tears, or other visible mechanical imperfections, in the manufacture of over 47,000 capacitors of the following types and sizes per American War Standard *C*75.3: molded *CM*30 and 55, 1,000-micromicrofarad silvered and stacked-foil; and *CM*35 and 60, 6,200-micromicrofarad stacked-foil capacitors; as well as potted *CM*70, 510-micromicrofarad transmitter-type capacitors. A total of eight capacitor manufacturers participated in the commercial trial, and the number that made specific types of capacitors and tests in each case is shown in Table V. This table contains a grand summary of test results and manufacturing experience in connection with the processing of electrically selected block mica into finished capacitors. It shows the number of capacitors that passed test requirements specified in American War Standard *C*75.3 and gives the results of other special tests.

Conclusions

Based on satisfactory Q, dielectric strength, insulation resistance, temperature coefficient, capacitance stability, radio-frequency heating, corona voltage, and life tests on these capacitors obtained

Figure 6. The mica Q test set developed by Bell Telephone Laboratories

Figure 7. The spark test locates conducting regions in block mica and permits defective material to be rejected before the application of the Q classification test

by eight participating manufacturers, it is concluded that electrically selected *E*-1, nonconducting block mica is suitable for use in the manufacture of all types and sizes of fixed mica-dielectric capacitors per American War Standard *C*75.3 up to and including *CM*70. However, nothing has been revealed by these studies which would indicate that such mica would not be equally as satisfactory for use in all sizes and types of capacitors, per American War Standard *C*75.3. Likewise, based on somewhat less extensive tests on electrically selected *E*-2 and *E*-3 nonconducting block mica, such mica within the limits specified for class *C*-2 and *C*-3 mica, per ASTM *D*-748–45*T*, is suitable for use in the manufacture of all types and sizes of capacitors up to and including *CM*60 per American War Standard *C*75.3.

The splitting quality and yield of satisfactory splittings and punchings of all lots of selected *E*-1 nonconducting mica of part 1 of the commercial trial, considered as a group, is estimated to be 10 to 20 per cent poorer than that reported for the lot *M*

Electric Drives for Steam-Electric Generating-Station Auxiliaries

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Synopsis: For several years there has been an increasing trend toward all-electric drives for steam-station auxiliaries on account of the recognized advantages in flexibility, convenience, low operating cost, and comparable investment cost. Substantial economies in first cost also have been obtained along with further improvements in flexibility through the use of transformers as the sole means of station power supply. Gratifying reliability of performance has been achieved by co-ordinating design, backed by extensive tests, including momentary interruptions of station power supply, and has been incorporated in approximately 500,000 kw of modern plants of the 850-pound 900-degrees-Fahrenheit powdered-fuel-fired unit type. Operating experience has demonstrated the over-all reliability and economy of all-electric drives for station auxiliaries and of the use of transformers as the sole source of station power supply.

Paper 45-151, recommended by the AIEE committee on power generation for publication in AIEE TRANSACTIONS. Manuscript submitted June 28, 1945; made available for printing July 30, 1945.

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THE INCREASING RELIABILITY of modern steam-electric generating stations has been an important factor in the dependable supply of electric power in the face of decreasing reserves and promises future economies in system investment. One of the vital elements of this reliability is the treatment of station auxiliaries and station power-supply equipment.

Before the advent of the extraction turbine, the need of steam for feed water heating strongly favored small steam turbines as drives for most of the station auxiliaries. Multistage bleeding brought about a critical examination of operating costs of turbine-driven auxiliaries, and resulted in the application of electric motors to many of them, certain steam-turbine drives being retained either to obtain convenient variable-speed operation or with the objective of securing greater reliability for critical drives.[1] The advent of modern steam pressures such as 850 pounds and above has resulted in even lower efficiencies for small turbines, unless they are made so complex that their reliability is seriously reduced.

Many factors have contributed to the improved reliability of electrically driven auxiliaries.[2] Modern motors are highly reliable, and variable-speed couplings provide flexible and efficient operation where required. The growing interconnection of both stations and systems makes it feasible to secure emergency electric power for auxiliaries not only from several points within a station but from remote sources as well. Several years' experience has demonstrated that the proper co-ordination of driven equipment, motors, control, and power source insure an extremely high degree of reliability. Many stations now operate with all auxiliaries electrically driven, with the minor exception in some cases of the turbine-bearing oil pump, which is furnished by the manufacturer as a part of the turbine.

Basic Requirements of Auxiliary Drives

The requirement of reliability for many auxiliary drives is most important. Especially with powdered-fuel-fired boilers, the interruption for even a few seconds of certain critical drives may result in flame extinction, and the resulting necessity of purging the furnace system and relighting may cause a serious (though temporary) loss of capacity. Thus the over-all system must be made relatively immune to short-time disturbances, but without sacrificing the simplicity and flexibility which are so essential to successful operation. Adequate safety interlocking is required but must be scrutinized for possible hazards to reliability.

For some of the drives variable-speed operation or its equivalent is necessary. Where storage capacity can be secured readily, the automatic intermittent running of constant-speed motors provides convenient, flexible, and low-cost performance. For other auxiliaries the use of constant-speed motors with variable-speed couplings can provide the desired solution.

India (good stained) sample. The poorest splitting quality and film yield was reported for selected *E*-1 nonconducting lot-*P* (heavy-reeved and ribbed) light-green mica of part II. This lot did not conform to the physical requirements of class *C*-3 mica per ASTM *D*-748–45*T*, but was included in the tests to study the performance of such mica. It is important to note, however, that the electrical performance of capacitors made with mechanically sound punchings from lot *P* electrically selected mica approached that obtained for the control sample. The poorest capacitor life performance was experienced with lot *R*, *E*-3 mica which did not pass the spark-test requirement but was included to check the *E*-3 range of the *Q* test set.

The proposed system of classifying block-mica quality based on a combination of dielectric and physical properties has been shown to be commercially reliable and practicable. This system differs radically from past practices, and previous concepts of mica quality considered suitable for use in capacitors. It does not discriminate against the presence of spots and stains in even first-quality electrically selected block mica, providing the mica conforms to specific electrical and physical requirements. Air inclusions and waviness also are permitted in the lower-quality classes, providing the mica meets specific electrical and physical requirements. Mica capable of meeting specific electrical and physical requirements also may be of any basic color.

The experimental work in connection with part I and II of the commercial trial on all lots of mica confirms that Bell Telephone Laboratories block-mica *Q*-test and spark-test sets or commercial equivalents* are satisfactory for classifying block mica in accordance with ASTM specification *D*-748–45*T*. Furthermore, the requirements for all classes of block mica, per this specification, have been found to be conservatively set, thereby providing a good factor of safety.

As the electrical system of classification qualifies mica previously considered unsuitable for capacitors, the mica supply for such use is greatly increased owing to the much more plentiful supply of lower visual-quality types of mica. An estimated saving up to 60 per cent of the total amount of good stained or better mica now used in capacitors is indicated.

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Though consideration of cost is secondary to that of reliability, a careful consideration of all factors will facilitate low-first-cost design without any measurable sacrifice in reliability. The low operating cost of electric-driven auxiliaries is inherent when compared with steam-driven auxiliaries.

Motor Application

By far the largest portion of motors used for station auxiliary drives are three-phase squirrel-cage induction motors conforming to National Electrical Manufacturers Association standards regarding starting current, starting torque, and maximum torque. In spite of the requirements of high reliability, only a very few motors and auxiliaries, such as boiler feed pumps, pulverizers, and circulating water pumps, are installed in duplicate. For this reason particular attention is paid to the mechanical and electrical construction of the motors purchased. This does not mean that the motors need to be of special design or construction.

Voltage Rating and Starting Characteristics

A few of the small motors are rated 220 volts, but most drives use either 440- or 2,300-volt motors. An economic survey taking into consideration the cost of motors, control equipment, and the station distribution system has resulted in a decision to place the dividing line between the use of 440-volt and 2,300-volt motors at approximately 100 horsepower.

Full-voltage starting is used for both 440- and 2,300-volt motors. This permits the use of a low-cost control scheme which is simple and direct in its operation and lends itself to quick automatic transfer from one power source to another in an emergency. It also provides full starting and pull-in torque for normal voltage conditions. It may, however, be necessary at times to start an essential auxiliary when the voltage at the motor terminals is below normal as the result, for example, of the loss of a sizable amount of generation from the system. The speed-torque requirements of all auxiliaries are given careful consideration, and motors having adequate speed-torque characteristics at the minimum operating voltage are selected.

For some applications, such as certain types of pulverizers, the starting torque is the critical value, and, if a motor is selected having adequate torque to start the pulverizer during low-voltage conditions, no difficulty will be experienced in bringing the pulverizer up to speed. In other applications, such as boiler feed pumps the starting duty is relatively light, but the torque curve of the pump may rise very rapidly with speed, and in this case it is necessary to check the speed-torque curve of the motor under minimum-voltage conditions to make sure that it remains above the pump characteristic at all speeds.

Motors having normal starting current usually are provided, as light flicker due to motor starting is not usually a problem when transformers are used for station power supply. Co-ordinated unit design results in satisfactory operation from the standpoint of disturbances resulting from starting the largest motor or the transferring of a group of running motors from one bus to another.

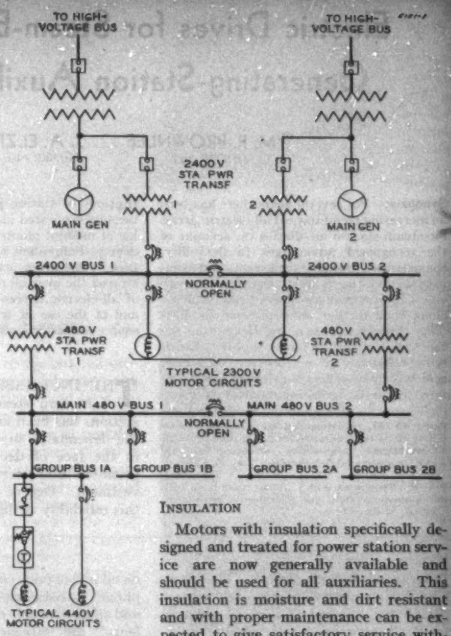

Figure 1. Typical power supply and motor connections for station auxiliaries

Mechanical Construction

In order to assure reliable continuous operation, careful consideration is given to mechanical construction. The motor windings and rotor bars must be braced to withstand the stresses due to full-voltage starting and must be thermally adequate for the current associated with it. Insofar as practicable the construction should be such as to provide ease in making periodic inspections and checks. This means, for example, that it should be easy to check the oil level in the bearings and to make sure that the oil rings are performing properly. Provision should be made for checking bearing temperatures, and suitable openings for checking air gaps are essential. Proper end play is important, especially in 3,600-rpm motors, and the motor should be so constructed that this can be checked readily.

Insulation

Motors with insulation specifically designed and treated for power station service are now generally available and should be used for all auxiliaries. This insulation is moisture and dirt resistant and with proper maintenance can be expected to give satisfactory service without the necessity of using splashproof or totally enclosed motors. Dripproof motors are provided where there is a possibility of water dripping on the motor.

Both class-*A* and class-*B* insulation are used. In general it is easier to obtain satisfactory class-*A* insulation for power-station service, and class-*B* insulation is specified only for motors operating in ambients above 40 degrees centigrade, such as draft fan motors.

Speed Control

For most station auxiliary applications constant-speed drives are used. The induced- and forced-draft fans are an exception to this. The power requirements of these fans are substantial, and their speed adjustment is controlled automatically by the combustion-control equipment.

In many of the earlier plants the motors for these drives were of the wound-rotor variable-speed type. However, equal efficiency and better control can be provided with constant-speed motors and variable-speed couplings of the hydraulic or magnetic type.[3] These are in most cases used to provide the entire range of speed control and have proved quite satisfactory, responding very well to the combustion-control equipment. In some instances two separate motors are provided with different constant-speed ratings, with dampers to provide intermediate control.

Power-Supply Systems

The choice of a system for supplying power to electrically driven auxiliaries is a vital one. The primary objective of adequate reliability must be obtained, but this does not mean that the most elaborate and expensive scheme is necessary or even desirable. One of the important advantages of electric drive for station auxiliaries in an interconnected transmission system is that power may be secured from a large number of sources and transferred instantly from a central location. The extension and improved performance of interconnected power stations and systems have increased the popularity of the unit system of plant design; that is, one boiler, one turbine, and one step-up transformer operating as a unit, with electric connections with other units made at the high-voltage bus only. The interconnected system can compensate for the loss of any one unit, and accordingly the statement has been made that the over-all reliability of the station auxiliaries need be no greater than that of the main units. This is true with certain minor exceptions. In the case of an emergency outage of a main generator for a temporary cause, it may be necessary to provide emergency service within a short time to the boiler feed pump. If the interruption to the main unit is long enough for the turbine to stop turning, then the availability of emergency power for the auxiliary turbine-turning motor will save a delay of two or three hours in restoring the unit to service

House Turbine, Shaft Generator, Transformer

In early applications of electric drive to include essential auxiliaries, it was sometimes thought necessary to provide an entirely separate house turbogenerator, supplemented with an auxiliary generator on the shaft of the main unit and a transformer source. Such an installation was so expensive as to offset in part the $1^1/_2$ per cent to $2^1/_2$ per cent reduction in operating costs achieved with electric drive. Experience soon showed that the costly house turbogenerator was unnecessary and added very little to reliability. The upward trend in steam pressures and co-ordinated bleeding cycles was also a factor in the gradual abandonment of the house turbine.

The less costly auxiliary generator driven on the shaft of the main unit is still much more expensive than a transformer. The principal advantage of the shaft generator is that the auxiliary bus supplied from it is not exposed to voltage disturbances originating on the transmission system. On the other hand the line starting of large induction motors from a shaft generator may involve serious voltage disturbances of several seconds' duration which are not encountered with transformer supply.

Careful analysis of fundamental requirements has shown that the proper co-ordination of the characteristics of motors and control with those of the driven equipment provides adequate reliability using transformers for the sole supply of auxiliary power. Some of the factors contributing to the improved reliability of systems using transformers are:

1. Co-ordination of control methods to avoid unnecessary interruptions.
2. The more rapid clearing of transmission-system faults.
3. The use of squirrel-cage induction motors with full-voltage starting.
4. The choice of power sources to provide a natural cushion against external power-system faults.

Special tests were made to check the over-all operation of the systems and subsequent experience provided further confirmation

Transfer Scheme With Unit System

Figure 1 illustrates a typical scheme of connections with the station power transformers connected to their respective main units at generator voltage and with the latter grouped in pairs for emergency operation of both sets of auxiliaries from either main generator. Transfer of an entire group of auxiliaries may be made from the control center and normally is accomplished automatically in case a station power transformer separates by differential relay. This automatic transfer also may be initiated by operation of the relays protecting the main transformer bank. Reliability suitable for a unit system is obtained with single busses which are well protected electrically and mechanically. In the case of the 480-volt system, the relatively large number of motors makes it desirable to divide them among group busses as shown so as to limit the total exposure on the main 480-volt busses. Experience to date has not shown the desirability of providing voltage-chasing schemes.

Influence of Voltage Dips During External Faults

The main step-up transformer of a unit installation provides a natural cushion for the station auxiliary bus against transmission faults. Figure 2 shows the positive sequence voltage on the station power busses as a function of the type of fault and its duration for short circuits immediately adjacent to the high-voltage bus. The initial voltage drop does not lower the pull-out torque of standard squirrel-cage induction motors below the normal full-load torque in case of these most pessimistic phase-to-ground or phase-to-phase faults. Even during three-phase faults adjacent to the bus the motors develop appreciable torque. With control properly co-ordinated the motors and

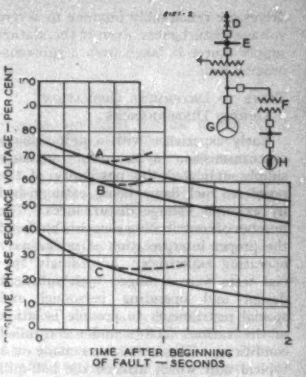

Figure 2. Influence of transmission faults on auxiliary-motor voltage

----------Effect of voltage regulator
A—Single phase to ground
B—Single phase to phase
C—Three phase
D—Fault
E—High-voltage bus
F—Station power transformer
G—Main generator
H—Motor

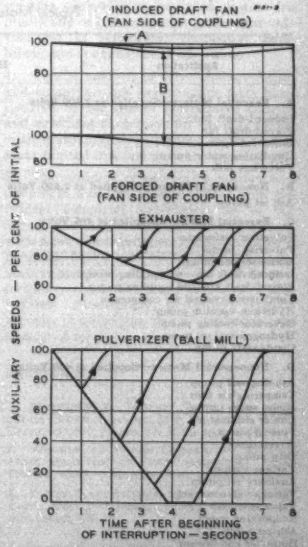
INDUCED DRAFT FAN (FAN SIDE OF COUPLING)
A
B
FORCED DRAFT FAN (FAN SIDE OF COUPLING)
EXHAUSTER
PULVERIZER (BALL MILL)
AUXILIARY SPEEDS — PER CENT OF INITIAL
TIME AFTER BEGINNING OF INTERRUPTION — SECONDS

Figure 3. Speed variations caused by power interruptions

A—Power restored at 2.3 seconds
B—Power restored at 3.7 seconds

drives are remarkably immune to severe voltage disturbances, even if the station supply source is taken from a subtransmission bus.

Tests to Determine Operation During Disturbances

Early experience with a unit using a subtransmission system for auxiliary supply indicated the possibility of the powdered-fuel flame being extinguished by external voltage disturbances. The number of contributing elements hindered the proper interpretation of preliminary operating experience. Accordingly special tests were arranged with sufficient design and operating personnel and special instruments to provide isolation of the various factors under controlled conditions. These tests were made on a typical unit which utilized the ball-mill type of unit pulverizers (two per boiler) to determine the influence of surges on the boiler operation. With one pulverizer (and two burners) operating at its maximum output, the entire group of boiler auxiliaries was intentionally interrupted for varying periods of time, checking the speed reduction of the different drives with oscillographs and recording indications of the boiler draft gauges with a moving picture camera.

At first the automatic transfer scheme was used to provide an interruption of some 18 cycles to the boiler auxiliaries. There was no observable difference in the flame performance and the speed changes were imperceptible. Fluctuations in the induced draft, forced draft, mill pressure, and mill differential could not be distinguished from those experienced for normal operation. The power interruption period was extended on subsequent tests to as much as six seconds. Figure 3 illustrates the speed reduction and return to normal of the various drives for the different lengths of power interruption. In no case did the disturbances themselves extinguish the flame, but after some five seconds the pulverizer exhauster slowed down sufficiently that the pressure responsive safety devices operated to close the emergency dampers and thus shut down the boiler. The inertia of most of the drives carried them through the interruption. The ball mill pulverizer running at slow speed slows down rapidly and comes to a complete stop in $3^1/_2$ to 4 seconds. However, the coal carried in suspension provides the necessary carry-over and subsequent restarting of the motor and mill is rapid.

Figure 4 illustrates the ratio of the total inrush current to the total normal load current of the auxiliaries and the duration of this inrush current as a function of the length of the interruption. It is seen that this automatic transfer of the auxiliaries involves no difficulties with inrush current or voltage reduction.

Table I. Steam-Plant Auxiliaries—Two Units

Typical Motor Classification

Application	Horsepower	Revolutions Per Minute	Number of Motors
A. Essential Motors—Supplied at 2,400 Volts			
Induced-draft fan	700	900	2
Forced-draft fan	350	1,200	2
Boiler feed pump	800	3,600	3
Circulating water pump	200	400	4
Pulverizer mill	250	360	4
B. Nonessential Motors—Supplied at 2,400 Volts			
Ash jet pump	100	1,800	2
C. Essential Motors—Supplied at 480 Volts			
Pulverizer exhauster	75	1,200	4
Pulverizer feeder	1	1,200	4
House-service pump	50	1,800	3
Induced-draft fan—oil coupling pump	2	1,200	2
Forced-draft fan—oil coupling pump	1	1,200	2
Combustion-control air compressor	$7^1/_2$	1,800	2
Hydrogen-vacuum pump	2	360	2
Generator-cooling pump	10	1,800	2
Hydrogen-seal oil pump	$7^1/_2$	435	2
Condensate pump	60	1,200	4
D. Nonessential Motors—Supplied at 480 Volts			
Ash-disposal pump	60	600	2
Tempering-air fans	$7^1/_2$	1,800	2
House sump pump	10	1,800	2
Cinder eliminator	20	1,200	4
Fuel-oil pump	2	1,200	2
Screen drive	3	1,200	2
Drip pump	1	1,800	2
Turbine turning	$7^1/_2$	1,200	2
Auxiliary oil pump	3	1,200	2
Various valve motors	2–$7^1/_2$		12
Vapor extractor	1	1,800	2
Evaporator pump	3	3,500	2
Ash-pit sump	2	1,800	1
House air compressor	60	1,200	1
Fuel-oil pump	5	1,800	1
Oil purifier	1	1,800	1
High-level tank pump	10	3,600	1
Battery-charging motor generator set	$7^1/_2$	1,800	1
Vacuum cleaner	20	3,600	1
Elevator	25		1

Control and Switching Schemes

As shown in Figure 1, 2,300-volt motors are connected to the bus through circuit breakers which provide automatic protection against faults in the motor or circuit (and in some instances thermal protection) and also serve as motor starters. Either air or oil circuit breakers of adequate interrupting ability are used, but the trend is toward the use of air circuit breakers because of their superior performance for starting duty. Air circuit breakers also have an advantage from the standpoint of inspection and maintenance of contacts. This is of considerable importance in view of the fact that these circuit breakers are operated much more frequently than circuit breakers on distribution circuits.

For 440-volt motors the control for many of the individual motors consists of a small air circuit breaker with instantaneous trip attachment for fault protection and a magnetic contactor for starting duty. For nonessential motors standard industrial control equipment is satisfactory. For some applications, however, latched-in contactors or air circuit breakers suitable for motor-starting service are required.

In a powdered-fuel plant it is necessary for safety and operating reasons that the sequence of starting and stopping certain motors be carefully interlocked. For example, the induced-draft fan is started first. This is followed in sequence by the starting of the forced-draft fan, the exhauster, the pulverizer, and the feeder. In order to avoid clogging of the fuel-supply system and to avoid a possible explosion if any piece of equipment in the afore-mentioned group is stopped, provision is made to stop automatically all of the motors ahead of it. In the above group, if the exhauster stops for any reason, its circuit breaker or contactor is opened, and an auxiliary switch trips the pulverizer, which in turn trips the feeder. It is essential that the device which initiates the tripping sequence respond to failure of the driven quantity and not simply to undervoltage, because stoppage may be the result of a sheared pin, a broken shaft, or some cause other than failure of power supply to the motor. In the example taken, the emergency dampers are tripped by the differential-pressure relay, damped to give a slight time delay. This in turn trips the exhauster motor and the remaining motors in the sequence.

Though undervoltage protection is not required for full-voltage starting motors, the use of standard magnetic starters for 440-volt motors would provide unintentional low-voltage protection. Most of

these starters will drop out at around 50 per cent of normal voltage and remain open, unless a latched-in type of auxiliary relay is used. This is not serious for automatic-start intermittent running equipment with storage capacity such as the feeder, house-service pump, combustion-control air compressor, and condensate pump, provided they are not included in any interlocking scheme. Standard starters even with latched-in auxiliary relays are not suitable for motors in an interlocked scheme, because the auxiliary switch on the contactor would start the tripping sequence of the other motors and emergency safety devices in the series. For such motors either latched-in contactors or circuit breakers suitable for starting duty are used.

Latched-in contactors or circuit breakers also are provided for highly essential motors, even though they may not be part of an interlocked sequence. This will permit utilization of all available power, even at voltages below 50 per cent of normal.

Protection of Motors and Circuits

Reasonably adequate devices of the relay type are available for the protection of 2,300-volt motors and circuits. However, for smaller 440-volt motors, it has been customary to employ devices designed for industrial use. These are usually of the thermal variety, based on extra protection to the motor, allowing for wide manufacturing tolerances in inexpensive equipment, different ambient conditions at the motor and the controller, unusual operating conditions, and so forth. This is not a suitable basis for central-station practice where conditions are materially different from the typical industrial installation. Proper co-ordination with driven equipment and mechanical protection of the motors and circuits is inherent in central-station design. Operators are able to devote more careful attention to the motors and drives, and maintenance is usually on a program basis. Conditions most likely to result in motor overloading usually will be detected through operating results.

Essential Versus Nonessential Motors

An essential motor is classed as one which, if interrupted, would cause a serious loss of unit output within a relatively short time. Induced-draft fans, forced-draft fans, boiler feed pumps, circulating water pumps, and pulverizer mills are examples of the larger essential drives. Some of the smaller units are just as essential, such as pulverizer exhausters and condensate pumps and to a lesser extent such drives as pulverizer feeders, combustion control air compressors, and even small 3/4 horsepower motors used to pump oil into the hydraulic couplings for the forced draft and induced-draft fans. Typical nonessential motors are ash-jet pumps, cinder eliminators, fuel-oil pumps, screen drives, evaporator pumps, house air compressors, and so forth. A typical list of essential and nonessential motors is given in Table I.

Types of Protection

Conditions found in central-station practice, together with improved reliability of properly applied motors, have led to the use of less protection for the motors with emphasis on eliminating unnecessary interruptions. For both essential and nonessential motors, instantaneous overcurrent protection is provided which will cover the entire circuit but will be safely above locked-rotor current. For essential motors this is the only automatic protection used, but thermal devices are provided to light warning lamps, so that the operator can take necessary steps to shut down the motor after making alternate provision for its drive. In the case of nonessential motors thermal devices are provided which will disconnect the motor but at values of current somewhat higher than found in industrial practice.

It is seldom practicable to provide positive locked-rotor protection for motors without risking unnecessary shutdown during normal starting. This is because under locked-rotor conditions, the motor does not have the inherent air cooling experienced in normal starting. Proper precautions will minimize the probability of locked-rotor conditions and alert operators usually can guard against the remaining ones.

There is a definite need for improved devices, especially for the protection of motors of the 440-volt class. Typical industrial devices are not sufficiently reliable, are subject to unsatisfactory tolerances, and are influenced by too many factors for the most reliable operation. There is also a need for a simple but positive method of locked-rotor protection.

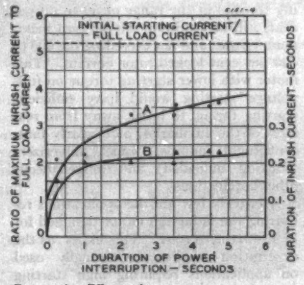

Figure 4. Effect of power interruptions on auxiliary-motor inrush current and its duration

A—Inrush current
B—Duration of inrush current

Conclusions

1. Experience over a number of years, including that with 500,000 kw of modern 850-pound 900-degree steam plants, has demonstrated the reliability and economy (both first cost and operation) of a station power system supplied from transformers rather than from house turbines or shaft generators.

2. In the unit system of plant arrangement, it is advantageous to connect station power transformers at generator voltage, so as to provide a natural cushion against transmission-system faults. However, this is not so necessary, if faults on the transmission system are cleared with modern relay and circuit-breaker speeds and the control system is properly co-ordinated.

3. The use of intermittent-running automatic-starting constant-speed motors for certain applications and variable-speed couplings for others results in the use of line-starting squirrel-cage induction motors for practically all drives with important advantages in reliability, simplicity, flexibility, and convenience in operation.

4. Careful analysis of drive characteristics and comprehensive performance tests have resulted in the use of inexpensive control and switching equipment for the many noncritical auxiliaries, with more costly equipment limited to a few essential applications.

5. The problem of protecting motors and circuits in a central station differs from the typical industrial application, as in the former the proper co-ordination of motors with drive characteristics, maintenance on a program basis, and close surveillance by station operators of equipment and its performance eliminates many causes of motor failures. Accordingly, in central stations schemes of protection should emphasize continuity of service.

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Central-Station Auxiliary-Drive Motors for Constant and Adjustable Speed

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IN SELECTING MOTORS for central-station auxiliary drives it might be of interest to note that the range of motor sizes for any particular voltage from the standpoint of reliable operation is much wider than the range when considered from the standpoint of a distribution system and the over-all economic situation including transformers, distribution system, switchgear, and motors.

Table I indicates what would be considered good practice, for the central-station auxiliary drives, from the standpoint of *motor design only*. Completely satisfactory motors can be built, with a maximum reliability for central-station drives, through the range of horsepower indicated at the commonly accepted voltage levels used in central-station auxiliary drive systems, as indicated in the table. Motor manufacturers build motors for the various voltages over a wider range than indicated. However, the table shows roughly the essentials of what might be called good central-station auxiliary practice.

Type of Motors

The great majority of motors used in central-station auxiliary drives, in new modern power-plant practice, are the induction type, although recently in smaller power plants with the advent of adjustable-speed couplings synchronous motors have been used to some extent. The use of d-c motors, in the large modern stations, is at present practically extinct.

The induction motors which are used for central-station drives can be divided readily into three classifications, the most widely used being the normal starting-torque motor. This type of induction motor is used and recommended, for nearly all of the major auxiliary drives, such as draft fans, boiler-feed pumps, condensate pumps, most pulverizers, and service and miscellaneous pumping applications throughout the station. Usually the motor will have a locked-rotor full-voltage inrush current of approximately 600 to 700 per cent of normal full-load motor rating. This design is commensurate with high efficiency, and power factor, adequate starting, and maximum torque. It is well suited for accelerating loads involving high inertias, which frequently arise in central-station practice on the induced-draft fans whose wheels are built very heavy to resist erosion. With the values of inrush current indicated, and with normal WK^2 or inertias, this motor usually is built with a starting torque in the range of 100 to 125 per cent. However, in the case requiring the motor to accelerate exceedingly high WK^2 requiring long accelerating periods, these motors may be designed with lower starting torques in the range of 50 to 60 per cent, still maintaining 200 per cent maximum torque, and not exceeding the 600 to 700 per cent locked-rotor current. This motor with lower starting torque on full-voltage starting would have sufficient starting torque to break away from rest most of the auxiliaries, particularly fans, centrifugal pumps, some pulverizers (starting unloaded) and miscellaneous other applications.

Relatively few are the applications requiring the induction motor designed for high starting torque. This motor, as the description implies, is normally used on applications requiring high starting torque, such as compressors starting loaded, or on some types of pulverizers, such as a ball-bearing type, which requires a very high starting torque, owing to the large bearings and massive construction. Other applications might be small air compressors, used for station service. It might be well to point out that the high-starting-torque motor should be checked carefully for high-inertia drives before being used, inasmuch as it might have very low-heat storage capacity in the rotor, which might make it unsatisfactory for this type of drive. High starting torque is sometimes confused with the ability to accelerate the inertia rapidly, reducing the starting time, and thus not requiring a motor which could accelerate the high inertia over a long accelerating period. The high-starting-torque induction motor could be used on some types of stoker drives which also require high starting torque but have low effective inertia.

The wound-rotor induction motor is used for adjustable-speed drives and constant or adjustable drives with especially difficult starting duties, which might require the starting of inertia beyond the ability of the normal-starting-torque induction motor, or loads which require a high starting torque beyond the ability of high-starting-torque induction motor.

The usual application of the wound-rotor motor, in central-station auxiliary drives, is for adjustable-speed drives on draft fans and boiler-feed pumps.

As previously indicated, synchronous motors are not used very extensively, with the exception of the drive for large low-speed air compressors, requiring compressor-shaft-mounted motors, wherein the low-speed synchronous motor, without base, bearing, or shaft, becomes the most economical drive for the machine. Synchronous motors have been used on a few occasions for driving special types of pulverizers, and at other times for driving large low-speed constant-speed condensate pumps In recent years, the most frequent application of synchronous motors has been found in the smaller power plants, for driving draft fans through variable-speed couplings of either the hydraulic or the electric type.

Usually, the small advantages, such as better power factor and possibly better efficiency, would not offset the disadvantages of increased costs and more complicated control.

In the future, with the increased size and pressure of central stations, larger and higher-speed boiler-feed pumps may come into use. If such is the case, the large two-pole synchronous motor, similar

Figure 1. Drip-proof sleeve-bearing normal - starting - torque squirrel-cage induction motor coupled to forced-draft fan

Paper 45-153, recommended by the AIEE committee on power generation for publication in AIEE TRANSACTIONS. Manuscript submitted June 1, 1945; made available for printing July 30, 1945.

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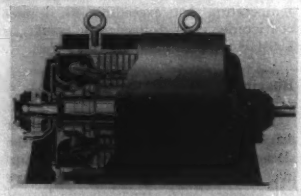
Figure 2. Splashproof sleeve-bearing normal-starting-torque squirrel-cage induction motor coupled to centrifugal circulating-water pump at end of steam condenser

Figure 3 (below). Base-ventilated high-speed sleeve-bearing induction motor

Longitudinal semisection showing typical construction



in construction to the turbine generator, may find application in central stations in the range of 2,000 horsepower and above. In this range and at 3,600 rpm, synchronous motors are less expensive than the induction motors of similar size and speed and should be equal in reliability at least to wound-rotor motors.

All the motors mentioned, both of the induction and synchronous types, are suitable for full-voltage starting. The inrush currents drawn, during the starting period are not excessive, particularly in view of the closeness of the motors to the source of generated power. The motor is satisfactory for withstanding the higher electric and mechanical shocks which occur on full-voltage starting even if they are repeated frequently. The motor shafts are liberally designed to have low tensile stress. The end turns are strongly supported by means of steel supporting rings, tie blocks, and binding. By this method the end turns are prevented from chafing and bending, which could cause mechanical failure of the insulation. Similarly by the proper use of insulation and slot wedges, the coils are prevented from making large movements in the slots, which might eventually cause failure owing to stresses encountered under starting conditions

Modern central-station auxiliary practice is to use full-voltage starting in nearly 100 per cent of the cases.

High-Speed Motors and Gears

For high-speed drives, particularly above 1,800 rpm, lower-speed motors with speed-increasing gears are occasionally used.

This is sometimes an economical solution to the question of what type of motor to use for high-speed drives, since a two-pole motor of the synchronous, induction, or wound-rotor type is more expensive than a lower-speed motor at its highest speed. It may be found that the two-pole motor costs about 50 per cent more in smaller sizes encountered in a central-station auxiliary drive and up to 100 per cent more in the larger sizes. In some cases, it is possible to purchase a gear for less than the difference between the cost of the two-pole motor and the most economical speed motor.

A drive consisting of a motor and a gear is entirely reliable, particularly for application to fans and pumps of the centrifugal type, which do not have any pulsating or reverse-torque loads, and which are infrequently started. If a high-precision-type gear is used under the foregoing circumstances, long life and high reliability usually result. The high-precision-type gear is mentioned in contrast to the usual industrial-type gear so frequently found in many industrial applications where reliability is not so important as in a central-station auxiliary drive. High-precision-type gears are the type used by the United States Navy for marine-propulsion applications.

Enclosures

For most of the applications encountered in a modern clean central station, it has been found that the dripproof motor, so constructed or protected that its successful operation is not interfered with when it is subjected to falling moisture or dirt, is entirely satisfactory and reliable. This is especially true for the auxiliaries, such as the draft fan, boiler-feed pumps, pulverizers, and most service and miscellaneous drives. Such a motor is illustrated in Figure 1 which shows a dripproof (open) motor, driving a forced-draft fan. This motor is protected against falling water. The dripproof construction also shields against accidental contacts with windings or rotating parts, and thus the motor is protected against accidental damage. This type of motor is furnished with split-sleeve-bearing end shields on both ends from 125 to 2,000 horsepower at 1,800 rpm. This construction greatly facilitates the maintenance of the motor by making it very easy to inspect or to change a bearing without removing the motor rotor from the stator, or without the necessity of pressing off the motor half of the coupling.

Other types of motors, such as splashproof, totally enclosed fan-cooled, base-ventilated, and totally enclosed motors with surface air coolers should be used if the ambient conditions justify the additional expense.

For application to auxiliaries, subject to continually splashing water (such as those which might be located in the lower part of the station), or in the case of auxiliaries located where it is necessary quite frequently to hose down the surrounding area, splashproof motors should be used instead of dripproof. A splashproof motor is shown in Figure 2 driving a circulating pump, and it can be seen that the major difference between it and the dripproof motor, is a different type of end shield, which is more protected from splashing water than is the dripproof motor.

Totally enclosed fan-cooled motors are not frequently used for central-station auxiliary drives, with the possible exception of motors used for coal-handling equipment. A motor of the open type exposed to coal dust will require frequent cleaning in order to prevent the coal dust from blocking the ventilating paths in and around the windings. Obviously, if these paths become blocked, the motor will overheat and eventually fail.

Similarly, where particularly dirty conditions are encountered, requiring too frequent cleaning of an open or dripproof motor (and in sizes too large for totally enclosed fan-cooled motors), base-ventilated motors, as shown in Figure 3, may be used if access is available to clean air below the motor. If not, a forced-ventilated motor, by means of duct work from a clean area, may be used; or in some

cases totally enclosed motors with surface air coolers may justify the additional expense, particularly if the heat picked up in the motor can be returned to the system heat balance.

It is well to bear in mind that any large high-speed motor, particularly a 3,600-rpm, probably will have a long stator and rotor stacking. Where such motors are required, it is necessary to consider the additional cost of totally enclosed forced-ventilated motors, or totally enclosed motors with surface air coolers, as well as the fact that the ventilating passages are more numerous and more difficult to clean than is the case when lower-speed large motors are used, which are more open, and consequently have ventilating passages more easy to clean. However, the probable longer life of the totally enclosed motor may offset its higher costs.

Explosion-proof motors seldom are required, as hazardous atmospheric conditions are not present in most stations. The possible exception is a coal-dust condition which might require a totally enclosed "dust- and explosion-proof" class-II group-*F* motor.

Insulation

In general, for central-station auxiliary drives, class-*A* motors, rated 40 degrees centigrade rise have given satisfactory service. For low voltages, 440 volts or below, motors are given an extra insulation treatment for boiler-room applications. For voltages 2,300 volts and above, the high-voltage insulation is usually adequate.

Ambient temperatures should be checked to determine if the temperature will be above the standard of 40 degrees centigrade. In some cases, even in new well-ventilated central stations, the ambient may exceed 40 degrees centigrade; for example, in case the motors driving the fans are installed directly over boilers, the ambient might reach 125 degrees Fahrenheit or over 50 degrees centigrade. In case dripproof motors are to be recommended or used, class-*A* insulation would not be satisfactory for the normal rated motor. In this case, a larger motor with lower resulting temperature rise could be used with class-*A* insulation, as long as the maximum total temperature did not exceed 90 degrees centigrade; or a motor of normal rating corresponding to the load requirements, could be used with class-*B* insulation, which would allow a higher rise with the maximum total temperature not exceeding 110 degrees centigrade.

Before one concludes that a larger-size motor, or a motor with class-*B* insulation is required, the ambient temperature should be weighted over the entire operating year.

Of course, if for other reasons, it is necessary to use forced ventilation or motors with surface air coolers, such that the air entering the motor is held at a temperature not exceeding 40 degrees centigrade, class-*A* insulation would be satisfactory even for these conditions.

Bearings

The great majority of motors used for driving central-station auxiliaries are the sleeve-bearing type. When properly applied and serviced, sleeve bearings have an excellent operating record and are highly reliable. They are available in motors ranging from the maximum to the minimum horsepower requirements. Rolling-contact bearings, on the other hand, are available only in a limited range of sizes and speeds.

Figure 4 shows cross sections of large high-speed pedestal bearings, used on high-speed motors driving boiler-feed pumps. This particular drawing is for a forced-feed lubricated bearing, and it will be noted that two oil rings are provided to lubricate the bearing initially when it is being started up, before the oil pump begins to deliver oil (in case the oil pump is directly connected to the motor shaft), and also to give some lubrication in case of forced-feed-system failure. The bearing is of the spherical type, and the double metal baffles of the labyrinth-type construction which prevent leakage of oil vapor along the motor shaft, can be seen. Sleeve bearings for lower-speed motors of the end-shield type of construction are similar to these, except that they are not of the spherical type and are not forced-lubricated. Spiral oil grooving, in the lower half of the bearing, is used instead of the rectangular oil grooves shown in Figure 4.

The oil deflectors machined in the shaft as noted in the axial cross section also serve to take a small amount of thrust for intermittent conditions. It will be noted that the babbitt or bearing material is "turned up" on the ends to furnish a rubbing surface for the small thrust collars. It is well to bear in mind that these thrust collars are for intermittent loading only, and have a very small thrust capacity, somewhere in the range of 200 to 300 pounds, for the larger motors. This point is often overlooked,

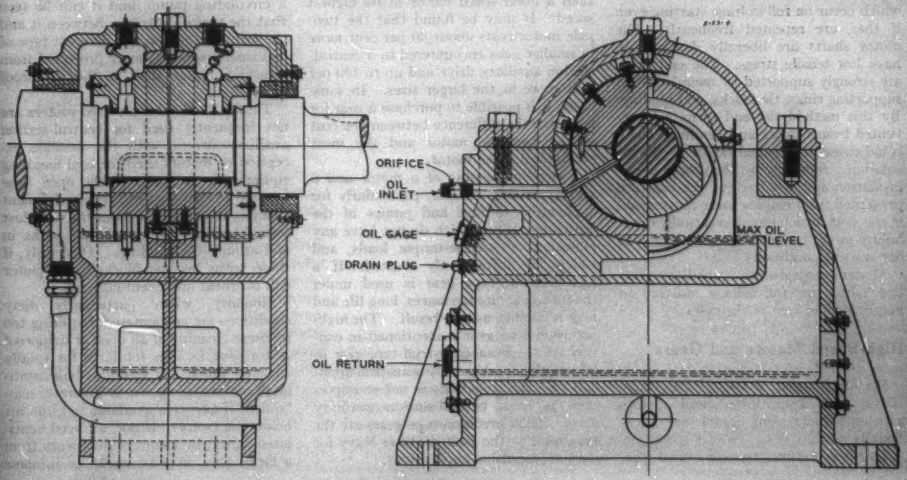


Figure 4. Sleeve bearing and pedestal for high-speed polyphase induction motor

Two vertical sections along and across shaft

particularly in applying couplings between the motor and the driven auxiliaries. As is known, nearly all types of couplings, even the so-called "gear" type, can and do transmit thrust under certain conditions of loading. Quite frequently the thrust which can be transmitted by the coupling, or which actually may be generated in the coupling, because of the transmission of torque, will exceed the allowable thrust capacity of the thrust collars. Another misconception often associated with this same problem is the amount of axial magnetic pull developed by the motor under normal full-voltage operating conditions. Obviously, when the motor is moved off the magnetic center an axial force is generated which tends to bring the motor rotor back to the magnetic center. However, this force is zero when the rotor is on magnetic center, and it increases as the rotor is displaced from magnetic center to some maximum value. For practical purposes, the maximum value which will be produced is very small, usually not exceeding 200 or 300 pounds, even on large induction motors. This maximum value often will occur at a displacement which may be of little use in preventing the wiping of a thrust collar when the motor is subjected to axial thrust.

Motors with rolling-contact bearings are available at 250 horsepower at 3,600 rpm and 400 horsepower at 1,800 rpm. Certain applications will require the motor to carry a high axial thrust, which necessitates the use of a rolling-contact bearing. Such an application might be a vertical pump motor in smaller sizes.

In general the use of sleeve-bearing motors is recommended for central-station auxiliary drives where thrust is not involved.

Adjustable-Speed Drives

For adjustable-speed drives for auxiliaries, there are available multispeed motors, wound-rotor induction motors with secondary control, constant-speed motors with adjustable-speed hydraulic or magnetic couplings, brush-shifting a-c motors, and d-c motors, utilizing adjustable variable-voltage Ward Leonard control, or adjustable variable voltage by electronic means.

At the present time, the wound-rotor motor with secondary control is by far the most widely used of any of the types of drives previously mentioned. In particular, the wound-rotor motor has been applied to the boiler-feed pumps and the draft fans.

When boiler feed pumps are driven by wound-rotor motors, they are usually arranged for a nominal speed reduction of 20 to 30 per cent. This relatively small speed reduction is satisfactory to give the necessary control of feed water over a wide range of load conditions. When the boiler-feed-pump system involves one constant-speed and one adjustable-speed pump, the required adjustable speed range may be greater than indicated.

Table I. Range of Horsepower for Motors at Commonly Accepted Voltage Levels Used in Central-Station Auxiliary-Drive Systems

Volts	Motor Rating (Horsepower)
220	Minimum requirements to 500
440	½ to 1,000
2,300	100 at 60 cycles, and up
4,000	250 at 60 cycles, and up

For draft fans, when driven by wound-rotor motors, the speed reduction usually has not exceeded 50 per cent of rated speed. Where wider speed ranges are required, wound-rotor motors can be furnished for speed ranges of at least 5 to 1.

It is believed, based on experience and observation, that the wound-rotor motor with secondary control is as stable and as reliable as any other type of adjustable-speed drive, and much more reliable than some of the available types. There is only one piece of rotating equipment required, and it is of standard construction, with no particular mechanical difficulties to overcome. The controlling equipment is of the nonrotating type and highly reliable.

Secondary control of either the metallic-resistor secondary and multipoint switch or the liquid regulator with an infinite number of steps can be furnished. Recent developments have reduced the size and increased the speed of liquid rheostats.

For motors of all sizes up to 1,000 amperes at 1,000 volts 20-point cam switches are available for secondary control. For motors 500 horsepower and below, secondary-speed-control switches up to 40 or 50 points can be furnished.

There has been some misconception in the past in regard to the stability of a wound-rotor motor, particularly at speeds below 50 per cent of rated speed, when it is operating with a fan or pump, whose torque curve decreases as the square of the speed. The wound-rotor motor is inherently stable, if by the definition of stability is meant that there is no tendency for hunting in the motor-torque characteristic, or there is no tendency for hunting when both the motor-torque characteristic and the torque characteristic of the load are considered. The wound-rotor induction motor has positive damping characteristics at low speed, as well as at high speed. It is true that the magnitude of this positive damping is lower at the low speeds, or, in other words, the drive inherently has more speed regulation at low speed than it does at high speed. This should not be confused with stability. Therefore, if the load torque does not change, there will be little or no cause for change of system speeds.

Table II was prepared to show the resultant system speed change, in per cent of running speed, which might be caused by certain changing conditions in the system of a draft fan. The conditions considered are:

1. A voltage change.
2. An arbitrary positive increment in fan-torque characteristic (the increment being equal at all speeds).
3. A change in the duct system resistance, such as change in the position of the dampers.
4. A change in the temperature of the flue gas.
5. Changes in secondary-resistor temperature.

For each of the conditions listed, two values of secondary ohms are shown, one value for approximately 75 per cent speed and the other for a 25 to 30 per cent speed, based on a fan or centrifugal-pump curve, with the torque varying as the square of the speed, and the load being equal to full load at rated speed. Also indicated is the change in fan- and motor-torque characteristics and the resultant change in system speed.

Figure 5 shows two fan-torque and two motor-torque characteristic curves. To analyze how Table II was derived, consider the intersection of curve 1 and curve 3. Curve 1 is the motor-torque characteristic curve with sufficient secondary resistance to result in 75 per cent of rated speed with the rated fan-torque characteristic. Similarly the intersection of curves 2 and 3 indicates that the motor operating with a value of secondary resistance results in a speed of 30 per cent with the rated fan-torque characteristic.

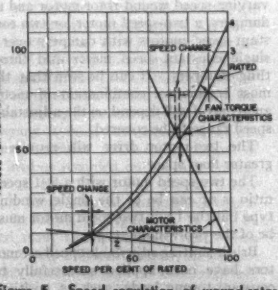


Figure 5. Speed regulation of wound-rotor induction motor driving a draft fan with change in fan load

1—Motor-torque characteristic, 75 per cent speed
2—Motor-torque characteristic, 30 per cent speed
3—Fan-torque characteristic, rated load
4—Fan-torque characteristic, 13.5 per cent overload

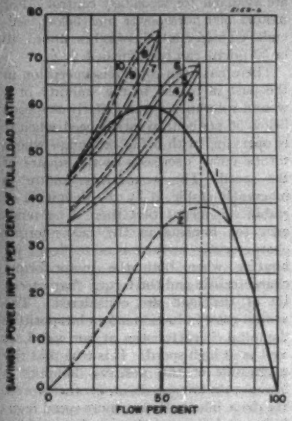


Figure 6. Input power savings of various types of driving motors and air-flow control over a constant-speed motor and throttling dampers

1—Wound-rotor motor
2—Constant-speed motor, inlet vanes
3—Two-speed motor, throttling dampers
4—Two motors, throttling dampers
5—Two-speed motor, inlet vanes
6—Two motors, inlet vanes
Curves 7, 8, 9, 10 are same as 3, 4, 5, 6, except that low speed is one half of rated speed instead of two thirds of rated speed

If the dampers are opened the fan-torque characteristic will be raised as shown by curve 4. If the same two values of secondary resistance are considered, the change in speed is evaluated from the intersection of curves 1 and 2 with curve 4, and this change in speed is expressed as a percentage of the speed resulting from the curves 1, 2, and 3, the values of the last column in the table will be found.

As will be noted, Figure 5 is for condition 3 for a 25-per-cent change in system resistance.

In all cases, the change in system speed is not considered a detriment. In the case of the 25-per-cent rise in stack temperature, the resultant speed increase will tend to offset some necessary manual or automatic speed change to compensate for the reduced weight flow, which will result at constant speed, but will increase gas temperature. For a fixed firing rate, the flow by weight probably should be held constant, even if changes do occur in the temperature of the stack gases entering the induced-draft fan owing to changes in position of superheater bypass dampers, and so on.

Table II. Resultant System Speed Change Which Might Be Caused by Certain Changing Conditions in System of a Draft Fan

Changed Condition	Secondary Ohms for	Torque Characteristic Change, Per Cent		System Speed Change, Per Cent of Running Speed
		Fan	Motor	
−5 per cent voltage	30 per cent speed	None	−10	−6
	75 per cent speed	None	−10	−1
Constant torque increase (drag)	30 per cent speed	+5	None	−2
	75 per cent speed	+5	None	−1.0
25 per cent system resistance	30 per cent speed	+13.5	None	−5.5
	75 per cent speed	+13.5	None	−2
25 per cent rise, stack temperature at 300 degrees Fahrenheit	30 per cent speed	−9	None	+3.6
	75 per cent speed	−9	None	+2.6
25 per cent rise, stack temperature at 500 degrees Fahrenheit	30 per cent speed	−13	None	+5.7
	75 per cent speed	−13	None	+3
200 degrees rise, secondary resistance	30 per cent speed	None	−1 to −2	−0.5 to −1.5
	75 per cent speed	None	−5	−0.5 to −1.5

Multispeed variable-torque motors are sometimes used for driving draft fans. In other cases two separate motors of suitable rating are used, one for maximum speed, the other for some reduced speed. The choice between a two-speed motor and two motors should be made on the basis of reliability, operating cost, first cost, and space requirements.

In the larger sizes, if one considers switchgear or control as well as the motors, first cost is about equal with the two motors showing a little lower first cost, especially if the two-speed motor is of the two-winding type, and the smaller of the two motors (considering the two-motor drive) is small enough to operate on low voltage while the larger must operate on the 2,300-volt or higher bus.

The separate two-motor drive might be considered to be more reliable, as the failure of one bearing or one winding would still allow the other motor to operate with damper control.

Figure 6 indicates approximate values of power savings using an adjustable varying-speed wound-rotor motor and no dampers, a two-speed motor, or two constant-speed motors with dampers over a single constant-speed motor and throttling dampers. It can be seen that the most economical combination of motor and control will depend on the adjustable speed range to be covered.

The two-motor drive will require a greater floor space.

The two-speed motor with a 2/1 speed ratio is or can be of the single winding type but the 1.5/1 two-speed motor must be of the two-winding type.

Brush-shifting adjustable-speed a-c motors have been applied successfully to constant-torque loads, such as positive-displacement fuel-oil pumps in oil-fired stations.

About the only place that an adjustable-voltage d-c drive is used in central stations at present is in the handling of the coal, such as in coal towers or skip hoists. The flexibility of the adjustable-voltage d-c control and the high accelerating torque of the d-c motors will provide more capacity per horsepower of motor in a coal tower than can be obtained with wound-rotor motor drive. This type of system results in low coal-handling-equipment maintenance, owing to the smooth accelerating and decelerating characteristics of the adjustable-voltage d-c drive, which eliminates all sudden increments of torque and consequently is much easier on the mechanical parts of the coal-handling system.

An adjustable-voltage d-c system can be designed in the case of coal-hoisting equipment, for future increase in coal tonnage, by increasing the hoisting speed.

Also, some figures are available to indicate that the adjustable-voltage d-c system takes less power from the distribution system than would an adjustable-speed a-c drive.

Recently some demand has been shown by manufacturers of both pulverizers and operating companies for an adjustable-voltage d-c drive for coal feeders, to operate from an adjustable-voltage system. Such a system takes power from three-phase or single-phase a-c power supply and rectifies the alternating current to direct current, and also of controlling the voltage by means of grid control on the thyratron rectifiers.

Such coal feeders probably would be associated with pulverizers which have little or no storage capacity in the pulverizers themselves, but which pulverize the coal at a rate depending upon the rate of feeding coal into the pulverizers.

Similarly, the same type of adjustable-voltage d-c drive has been quoted for small stokers to operate in conjunction with combustion systems.

Such applications have not been made in central stations in sufficient number and for a sufficient length of time to give any comments in regard to the success and maintenance record of such drives, although the record is excellent in other industries.

Automatic Regulation of Turbine Generators to Relieve Power-Supply Systems of Steel-Mill Load Swings

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Synopsis: Certain steel-mill loads are fast, cyclic, and of considerable magnitude. Given a set of conditions involving such a load, a relatively small steel mill, speed-controlled generating capacity all connected to a large power-supply system, much of the swings in the steel-mill load will be taken by the large supply system. Of itself, this result may not assume special importance. When transmissions in the large power-supply system, well-loaded under steady-state conditions, are involved, and speed governing of the system is at the remote end of the transmissions, the cyclic loads tend to reappear in the transmissions. These circuits may, according to their finite transmitting abilities and the swing peaks imposed on them, be unable to carry the peaks without undesirable voltage depressions or cause undesirable frequency variations on the system. Generation of power from by-product fuels in a steel mill is generally economical but is dependent on the continuity and quality of the nonstorable fuel as well as on the steaming and generating capacity installed. Relief to a large power-supply system from the cyclic load swings normally carried by that supply system has been made possible by a new static load control and hydraulic servomotor to cause the steel-mill turbine generators to respond to the regulator. The combination has been applied successfully to two 20,000-kw turbine generators, causing one or both to take a base load, a percentage of the variable load, and to modify their total loads according to available steam pressure. The turbine-generator response can be as high as 5,000 kw per second on each unit. High-speed charts show the loads on the various circuits with and without the load control in operation.

The Basic Problem as Seen From the Standpoint of Power Systems Interconnected by Circuits of Finite Transmitting Capacities*

SUPPLYING POWER to large hot-strip continuous-rolling mills such as are now used so extensively in steel mills to produce wide thin-gauge metal strip has presented a new problem to the electric-power industry. The power drawn by a large continuous hot reduction mill is characteristically cyclic and, starting with the introduction of the slab, may build up to 25,000 kw in a period of ten seconds, stay nearly constant at peak value for a period of 40 to 60 seconds during the sojourn of the metal in all of the rolls, and then fall off to nearly zero in another ten-second period as the strip moves out of the rolls. This is followed by an idle period approximately equal to the rolling period while the succeeding slab is being oriented. The cycle then repeats itself, usually at the rate of 25 or more times per hour, depending on the size of the slabs.

A heavy cycling load of this kind, if not absorbed before it gets into the connected utility system, will produce: (1) wide frequency variations on an isolated system or (2) wide load swings on the tie lines of interconnected utility systems.

This problem is exemplified by the effect on the system of the Alabama Power Company of a 48-inch six-stand continuous hot-strip mill operated by the Tennessee Coal, Iron, and Railroad Company at their Fairfield plant near Birmingham, Ala. The steel company purchases power from the Alabama Power Company to supply its load requirements over and above the output of its own steam-generating plants which are fired principally with blast-furnace gas. As the availability of blast-furnace gas bears little relationship to the variable power-load requirements of the steel mill, the power taken from the Alabama Power Company system, consequently, is extremely variable. The cyclic nature of this load as recorded on the high-voltage side of the 70,000-kva 110/44/6.6-kv supply bank with the strip mill in operation is shown in Figure 1. It will be noted from this load chart that, when the hot-strip mill is shut down, the balance of the steel-mill load is comparatively free of rapid cyclic load swings, indicating that the loads of the other steel-mill production processes are not only well diversified, but also of smaller magnitude and less violent than the hot-strip-mill load cycle.

If the Alabama Power Company system were operated isolated from other utility systems, the effect of these load swings would be to produce wide frequency variations, probably of the order of plus or minus two tenths of a cycle, and the control problem would be primarily one of frequency control, as no tie lines would be involved. Isolated operation, however, is distinctly an abnormal condition, because the economics of interconnected operation between power systems, achieved through the minimization of generating reserves, the utilization of load diversity, and the interchange of economy energy between systems, long ago dictated the closure of tie lines as a normal operating condition between neighboring power companies in the Southeast and adjacent areas. As interconnections are extended between utility systems, thereby bringing more rotating equipment into parallel operation, the system flywheel effect is increased, and frequency variations from load changes become less pronounced, but wide load swings appear on the interconnecting tie lines, and the control problem then becomes predominately one of tie-line load control on the local systems. This is demonstrated very clearly in Figure 2 where frequency and tie-line loading are shown for both isolated and interconnected operation under identical load conditions.

As the Alabama Power Company's load-control problem is affected by the extent of its interconnections with other systems, a brief description of these interconnections will be in order. The Alabama Power Company together with the Georgia Power Company, South Carolina Power Company, Mississippi Power Company, and Gulf Power Company constitute the completely integrated Southern Group of systems of the Commonwealth and Southern Corporation, having a combined diversified peak load in excess of 1,250,000 kw, of which over 40 per cent is in Alabama. This Commonwealth and Southern composite system is normally interconnected through several ties with power systems in Florida on the South, and through three tie lines with the system of the Tennessee Valley Authority on the North. The Tennessee Valley Authority system, in turn, is normally tied in at Memphis, Tenn., with the interconnected group of power systems in the Southwest, and with the interconnected power systems in the northcentral area at Louisville, Ky.

This combined group of power systems, located in 24 states, normally is operated interconnected and has an estimated peak load of approximately 16,000,000 kw, not including the loads of large industries

* Prepared by W. W. Eberhardt.

Paper 45-113, recommended by the AIEE committees on automatic stations and power generation for publication in AIEE TRANSACTIONS. Manuscript submitted April 11, 1945; made available for printing May 14, 1945.

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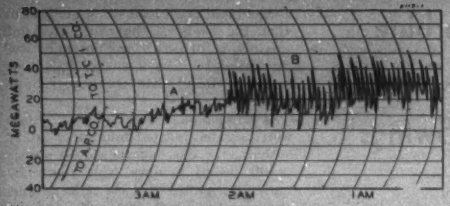

Figure 1 (above). Typical wattmeter chart of power supply to Tennessee Coal, Iron, and Railroad Company by Alabama Power Company

A—Hot-strip mill shut down
B—Hot-strip mill in operation

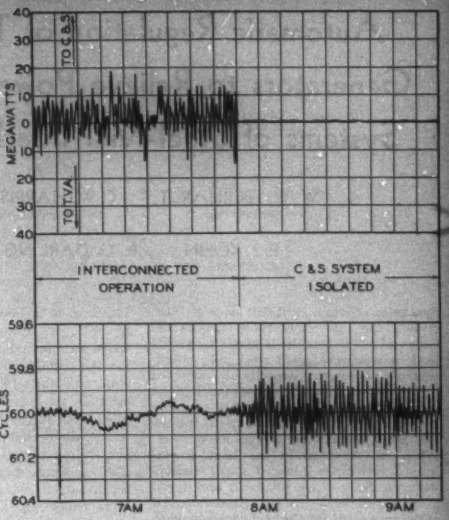

Figure 2 (right). Alabama Power Company system frequency chart and Commonwealth and Southern–Tennessee Valley Authority tie-line wattmeter chart for open and closed operation of tie line

carried on their own plants operating in parallel with the public utilities. While the torque-versus-frequency characteristics of this system as a whole have not been determined, a fairly close estimate can be made from tests and observations taken on the major portion of the system. In 1937 a series of tests was carried out on the portion of the interconnected system east of the Mississippi River extending from the Great Lakes to the Gulf of Mexico, during which speed was quickly varied 0.1 to 0.2 cycle by the regulating plant with all generator and tie-line regulating devices out of service, and the change in kilowatt output noted. For either increases or decreases, the change in kilowatt output was about one per cent per one-tenth-cycle variation in frequency. Different results may be obtained as the interconnection is extended and may vary over a period of years, if the ratio of motor load to noninductive load changes. The reason for this is that a noninductive lighting or heating load does not vary with frequency, provided constant voltage is maintained, whereas a motor load does. The load on the interconnected system has grown considerably during the past eight years and especially so during the last four years with the addition of war industries with heavy motor loads. It reasonably may be assumed, therefore, that the load variation per one-tenth cycle of frequency variation still represents a change of at least one per cent, if not more.

On the basis of the one-per-cent figure, a 25,000-kw load swing in the 16,000,000-kw system total load would vary the frequency 0.0156 cycle. This variation hardly would be noticeable on the interconnected-system frequency, as it would not ordinarily be outside of the normal-frequency band width. Variations in loading of the close-in tie lines, due to such a load swing, however, are very pronounced and have created a difficult regulating problem when the swing is more rapid than the response time of the tie-line regulator.

When interconnections first were made about 15 years ago, joint regulation of frequency was attempted, but the results were unsatisfactory, because of tie-line tripouts due to overloads. This was due to the fact that load swings were shared in the various areas regardless of where the swings originated. The resultant load transfers over the tie lines were such that no definite value of tie-line loading, in the form of either load or capacity, could be scheduled and maintained. Based on experience and operating results over the years, it has become the accepted practice normally to assign the frequency regulation to a selected plant or system located near the interconnected load center and require all other systems normally to hold their tie-line loads on predetermined schedules towards that area. The frequency-regulating plant and the various tie-line-regulating plants complement each other in that close frequency regulation makes possible equally close adherence to tie-line schedules, and, conversely, if all tie lines are held on schedule, each system, by necessity, has to absorb its own load swings and thereby assist the frequency-regulating plant to the fullest extent in the control of frequency. In addition to assisting the frequency regulation, close tie-line regulation is also essential in obtaining maximum tie-line loading without risk of tripouts due to overload swings when large blocks of energy are being moved. This is a very important consideration, because tie lines, by necessity, are of finite transmitting capacity, depending on the economic considerations involved in the interconnection, and usually have a capacity rating less than ten per cent of the generating capacity of either of the participating systems.

Since the frequency regulation for the interconnected system ordinarily is assumed by plants in the northcentral area, the regulating problem of the Commonwealth and Southern group, therefore, becomes that of regulating the tie lines between it and the system immediately on the north, which is the system of the Tennessee Valley Authority.

The load south of the Commonwealth and Southern–TVA tie lines is approximately 1,600,000 kw including the Florida system, or approximately ten per cent of the whole interconnected-system load. On this basis 90 per cent of any instantaneous unbalance between load and generation in the Southeast is reflected north through the Commonwealth and Southern–TVA tie lines and ten per cent of any unbalance in northern and southwest areas is reflected south through the same ties. This apportionment of load swings applies only before governors and load controllers have had time to function. It is evident, therefore, that 90 per cent of rapid load swings in the Southeast, such as the type caused by continuous strip-mill operation, which are faster than the response time of tie-line regulators, will be reflected through the ties unless the tie-line load controller is nearly instantaneous in action.

Fast tie-line regulation is only possible in the ideal case where only a single tie

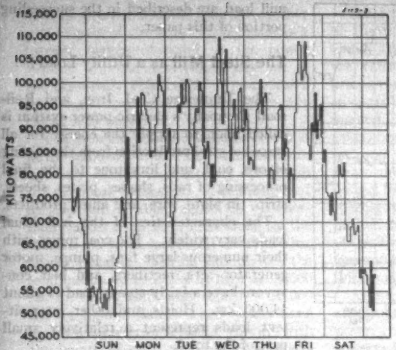

Figure 3. Typical hourly power demands of the Tennessee Company

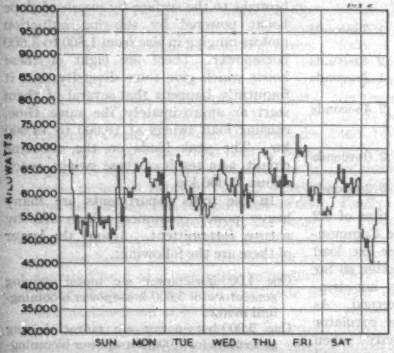

Figure 4. Typical hourly generation of electric power by the Tennessee Coal, Iron, and Railroad Company

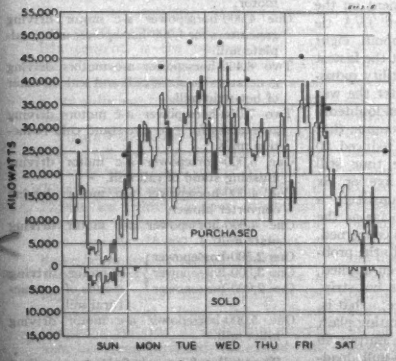

Figure 5. Typical unregulated hourly demands of the Tennessee Coal, Iron, and Railroad Company upon the Alabama Power Company (circles indicate maximum 15-minute daily demands)

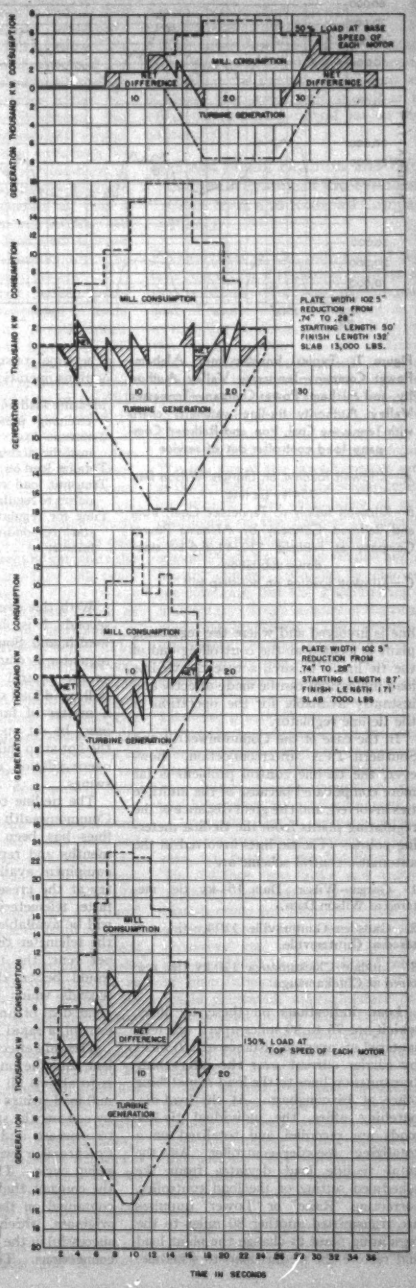

Figure 6 (right). Probable effect of an "anticipator" operating a conventional synchronizing motor of a turbine generator having a response of 2,000 kw per second (time lags in relaying neglected)

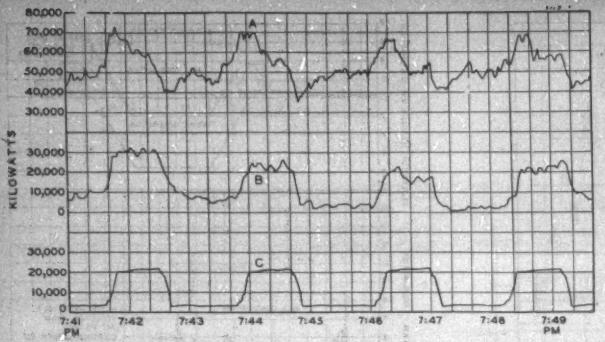

Figure 7. Typical hot-strip mill, Alabama Power Company–Tennessee Valley Authority, and Alabama Power Company–Tennessee Valley Authority tie-line wattmeter charts with Tennessee Coal, Iron, and Railroad Company load controller out of service

A—Kilowatt loading on Gorgas–Wilson Dam 154-kv tie line

B—Kilowatt supply to Tennessee Coal, Iron, and Railroad Company by Alabama Power Company at Fairfield 110/44/6.6-kv step-down substation

C—Kilowatt loading on hot-strip mill

line is involved and where the regulating plant is located at the controlling end of the tie line. In such a case the tie-line load indications can be made directly and instantly available for the operation of the tie-line regulator.

In the case of the Commonwealth and Southern–TVA interconnection, however, the tie-line control problem is far more complicated because of the multiple ties involved, and the great distance of the regulating plants from the tie-line metering points. The tie lines involved in the automatic-control scheme are:

1. Gorgas–Wilson Dam 154-kv tie, metered at Wilson Dam.
2. Gadsden–Guntersville 110-kv tie, metered at Guntersville.
3. Lindale–Chickamauga 110-kv tie, metered at Chickamauga.

Load indications on these tie lines, which are 75 to 90 miles apart, are telemetered an average distance of 150 miles by carrier current over the intervening transmission lines to the load-dispatching office at Birmingham. At the load-dispatching office, the individual tie-line loads are recorded and totalized on a totalizing recorder–controller. As the total tie-line load deviates from the scheduled setting of the load controller, correcting "Raise" or "Lower" impulses are transmitted another 80 miles to the regulating plant to change the plant load and restore the tie-line load to schedule. The time consumed in completing these various operations is as follows:

Measure load on tie line at interchange point	1.2 seconds
Transmit load indication to load-dispatching office	2.4 seconds
Totalize load on three tie lines	1.2 seconds
Transmit load correcting impulses to regulating plant	2.4 seconds
Time for regulating plant to start responding to control impulse	2.0 seconds
	9.2 seconds

With this over-all response time of 9.2 seconds, it is obvious that the Commonwealth and Southern–TVA tie-line load regulator is completely ineffective so far as the control of continuous hot-strip-mill rapid load swings are concerned. As a matter of fact, the tie-line regulator must be set on "Low sensitivity" when the hot-strip mill is in operation to avoid overregulation or magnification of load swings.

The tie-line control equipment on the Commonwealth and Southern–TVA tie lines has been in service about eight months and represents about the fastest equipment available to the utility industry at the present time. After the war faster telemetering schemes undoubtedly will be available, but, if we assume that the telemeter time could be reduced 50 per cent, the total response time still would be on the order of five or six seconds which would not constitute a great deal of improvement so far as the control of rapid load swings is concerned.

The only effective solution to the problem, and the one that has been applied, is to absorb all or part of the hot-strip-mill load swings at their source: that is, by causing the steel-mill generating plant to increase and decrease its output in synchronism with the strip-mill load-swing cycle. This, in principle, satisfies the concept that disturbances should be contained on the system on which they originate, which concept has proved so successful in the operation of utility interconnections. The elements of the steel-mill load are described in the succeeding portion of this paper.

The Steel Mill as a Utility Load†

The Tennessee Coal, Iron, and Railroad Company's electric-power system is called upon to supply the energy for all stages of steel production from the mining of ore, coal, and limestone to the final processing of rails, shapes, plates, sheets, strip, tin plate, wire, and allied products.

The characteristics of the individual loads vary widely. The coal mines with their numerous large fans, pumps, motor generator sets, rectifiers, and belt conveyors have a fairly steady load of about 14,000 kw. Hoists and other intermittent loads represent a relatively small part of the total.

The ore mines have a widely fluctuating load owing to the fact that the ore is brought to the surface by means of slope hoists powered by slip-ring induction motors ranging in size from 1,800 to 3,500 horsepower. There are eight of these hoists which give some diversity, but it frequently happens that several of them start at approximately the same time, causing load swings of 10,000 to 14,000 kw. The peak loads on the ore-mine circuit, as a result of these swings, reach about 35,000 kw.

In the mills departments are many heavy power consumers which are, by nature, intermittent. Among the larger of these are the following:

One 4,000-horsepower a-c motor driving generators for 5,600-horsepower blooming-mill motor.
One 5,000-horsepower a-c motor driving generators for 7,000-horsepower blooming-mill motor.
One 6,000-horsepower a-c motor driving generators for 7,000-horsepower plate-mill motor.
One 4,900-horsepower a-c motor driving generators for 4,000-horsepower universal-plate mill.
Two 8,400-horsepower a-c motors driving generators for six stands and scale breaker of hot-strip mill.
Two 7,050-horsepower a-c motors driving generators for two five-stand cold-reduction mills.
One 5,000-horsepower a-c motor driving finishing stand of rail mill.
One 4,000-horsepower a-c motor driving converter blower.
One 4,000-horsepower a-c motor driving plate mill.
One 2,500-horsepower, One 3,000-horsepower, One 2,000-horsepower } a-c motor driving stands of a structural mill.
One 5,000-horsepower a-c motor driving billet mill.

The mill rolling schedules are worked out to have as few as possible of the heavy power consumers operating during the same shifts. However, there are not enough idle shifts for the several mills to

† Prepared by C. W. Harrison.

prevent most of them operating together a good part of the time. The result is a rapidly varying demand on the power system. As the steel enters any one of the previously listed mills, a momentary peak equal to or greater than the motor rating may result.

The greatest concentration of power is in the hot-strip mill. The peaks here are not only higher than for any other mill but are more consistent. The idling load on this mill is about 3,000 kw. It normally takes from 10 to 12 seconds for the steel to reach the last stand after entering the first stand. During this period, the load builds up to peaks as high as 25,000 kw for heavy slabs and 15,000 or 18,000 kw for lighter slabs. These peaks hang on for a number of seconds, varying with the length of slab, and fall off at about the same rate that they came on. When rolling a large order of the same size slabs, the load swings come with clocklike precision. The number varies from about 25 per hour for some of the long heavy slabs to over 100 per hour for some of the short ones.

The composite load from all departments of the Tennessee Coal, Iron, and Railroad Company is one that changes from day to day and from hour to hour. Figure 3 shows hourly demands for a week, picked at random. It will be seen that on Sunday this ranged from 49,000 to 75,000 kw. On weekdays, the range was from 64,000 to 110,000 kw. Each of these hourly figures represents the integrated total of a load with momentary swings having at times an amplitude in the neighborhood of 40,000 kw.

The Tennessee Coal, Iron, and Railroad Company's generators consist of three 20,000-kw units at the main power station of the Fairfield Steel Works and five units totaling 18,500 kw at the Ensley Steel Works power stations. As blast-furnace gas, which fluctuates both in volume and Btu content, is the primary fuel, and blast-furnace auxiliaries have first claim, the steam available for electric generation is not sufficient to maintain a steady output.

Figure 4 shows the total hourly generation of all the foregoing generators for the same week as was covered by Figure 3. This shows a variation from 50,000 to 72,000 kw which is not exceptional. There are times when the hourly generation exceeds 75,000 kilowatt-hours or drops below 40,000 kilowatt-hours.

Obviously another source of power is necessary to meet the demands of the Tennessee Coal, Iron, and Railroad Company system. If additional generators had been provided, additional boilers using fuel, other than blast-furnace gas, would have been necessary. The alternative was to purchase the additional power from the Alabama Power Company. To date, it has been found economical to purchase, rather than generate this power.

The procedure has been to operate two of the 20,000-kw machines, speed-governed, at or near their full capacity with the third 20,000-kw unit governed by pressure and allowed to generate as much as possible from whatever steam remained. Under such conditions the generation of this third machine swings up and down following variations in steam pressure rather than variations in system load. The small Ensley units are speed-governed and generate all that a limited supply of steam will permit. All of the Tennessee Coal, Iron, and Railroad generators operate in parallel with the Alabama Power Company system.

As might be expected, sudden power swings have been largely passed on to the power-company system. A small speed-governed power system inherently will not rush in and grab a large part of a sudden load from a large power system where the two are operating in parallel, unless special provisions are added to force it to do so. The small system, at best, normally will take little more than its pro-rata share of the new load based on the relative sizes of the two systems. If, as previously outlined, the small-system turbines already are running nearly wide open under speed regulation or held in check by pressure regulation when the upswing of load occurs, they will practically ignore the swing.

Figure 5 covering the same period as Figures 3 and 4 shows the interchange of power between the two systems. This chart, like Figures 3 and 4, shows the one-hour demands. Momentary peaks and valleys are, of course, much higher and lower than the values shown. The circles show the maximum 15-minute demand for each day. It is interesting to note that, during some hours over the weekend, the power flow was in both directions.

The contract between the power company and the Tennessee Coal, Iron, and Railroad Company has some special features to cover local conditions but basically consists of an energy charge for kilowatt-hours purchased and a demand charge. At present the demand charge is based on 50,000 kw and is a fixed amount so long as the 15-minute demand does not exceed 50,000 kw. In the event of an overrun, the new demand becomes the billing demand for that and the 11 succeeding months, provided another overrun does not occur during that 11-month period. A schedule is worked out for taking off the Tennessee Coal, Iron, and Railroad Company turbines for repairs during periods of the year when water power is most plentiful. At such times, a definite additional or seasonal demand is permitted over and above the 50,000-kw firm demand previously mentioned. A fixed charge is made for this seasonal demand.

Such in brief were the load conditions, the generators available, and the power-contract features which existed at the time the load control was installed.

The succeeding portion of the paper states the nature and sources of energy available in the Tennessee Coal, Iron, and Railroad Company plant as well as the effect the new load control has on these sources.

Fuel and Steam Facilities and Effect on Steam System of the Tennessee Coal, Iron, and Railroad Company Plant†

The action of the peak-control regulator, operation of the steam turbines, and the resultant effect on electric-power generation are wholly contingent on the availability of steam with which to meet the cyclic peaks. As no additional steam-generating equipment or accessories were added when the regulator was installed, the method used and the effect on the existing steam-generating and consuming units are worthy of comment.

At Fairfield are three blast furnaces. The top gas of the three furnaces serves as the primary fuel for the steam-generating station. The availability of gas is contingent on the number of blast furnaces in operation. Not only is there a seasonal variation in gas volume and Btu heating content, owing to the change in the coke rate, but also a fluctuating and momentary change because of the furnace operating conditions. The furnaces are alternately checked each half-hour for approximately one minute. During the checking periods, practically no gas is generated from the furnace checked. Likewise, practically no gas is generated during the casting periods of the furnace which requires about ten minutes, four times each day. During periods of furnace delays, such as changes of tuyères and blow pipes, no gas is generated.

Approximately 14 per cent of the top gas is utilized at practically a constant rate for heating the hot-blast stoves. The balance, less leaks and waste, is available for steam generation. The blast-furnace gas supplied to the boilers is supplemented with a limited amount of pulverized coal and natural gas during prolonged high-load periods and intervals of blast-furnace gas shortage. Of the steam generated, approximately 34 per cent is used by the three turboblowers and miscellaneous users, leaving 66 per cent of the steam available for electric generation.

The turboblowers and miscellaneous users have first claim on the steam. The balance of steam available for electric current is subject to wide variations and fluctuations. The mill and mine electric loads also vary but bear no relations to the steam availability for electric generation.

Prior to the operation of the new load control and to utilize the widely varying

† Prepared by E. J. Kohn.

and fluctuating volume of blast-furnace gas to full advantage, a steam-pressure regulator had been used which, in effect, maintained a constant steam pressure on the entire system by loading or unloading the turbogenerators in steps of 500 kw. When the new load control went in service, the old steam-control regulator was limited to the number 3 20,000-kw turbogenerator. To meet the peak demands for electric power, the steam, when required by the turbogenerators, must be available for instantaneous use. A gas holder, for the storage of blast-furnace gas, even if practicable, would not be of help in meeting the peak load, as the time element needed to generate steam in response to the peak load is too great for the existing boilers to carry all peak as well as a portion of the base load. An isolated boiler would be impractical as steam would only be utilized during the intervals of mill peak loads. During the off-peak loads, the steam would be lost at the relief valves of the boilers. Firing the boiler as required to meet the peak demand is impractical owing to the time element involved in generating the varying rate of steam and the time lag in the control equipment. An ample steam receiver, if practical, would be of advantage in meeting the peaks. The pipe lines serve, in part, as such a receiver. Supplementing the limited receiver capacity of the piping system, the boilers act as a heat flywheel and generate steam by flashing of the water stored in the boiler, due to the lowering of the steam pressure.

Normally the boiler steam pressure is maintained at 335 pounds per square inch by the steam-pressure regulator previously mentioned. With the new load control in service, the boiler steam pressure is pulled down to a new level, and a quantity of water in the boilers is flashed into steam. This added steam supplies the requirements for meeting the peak demand imposed on the generators. The magnitude and duration of the permissible peak demand determine the added steam requirements. The extent of generation by the Tennessee Coal, Iron and Railroad Company of the peak is determined largely by the permissible drop in steam pressure and the duration of no-peak load. The latter enables the boilers to recover full steam pressure in anticipation of rolling the next slab. The number, type, and size of the boilers, or in other words, the steam-releasing space and water storage in the boiler for flashing determine the permissible drop and ability to recover steam pressure. The type of control valve supplying the feed water to the boilers further influences the steam-releasing space in the boiler.

The steam-generating equipment consists of eight Babcock and Wilcox boilers of the four-drum type with integral two-drum economizer. Five of the boilers each have three 42-inch steam drums and one 48-inch mud drum with a heating surface of 14,607 square feet and a normal output of 134,000 pounds steam per hour with blast-furnace gas as fuel. Three of the boilers each have three steam drums 36 inches, 48 inches, and 42 inches in diameter and one 48-inch mud drum with a heating surface of 19,800 square feet and a normal output of 170,000 pounds per hour with blast-furnace gas as fuel. All eight boilers are equipped with superheaters. Normally only seven boilers are in service. With one of the larger boilers out of service the effect on steam generation and the ability to meet the peak demand is noticeable and accordingly reduced.

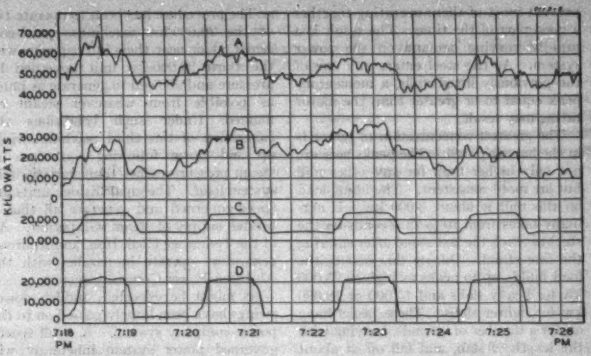

Figure 8. Typical hot-strip-mill regulating generator, Alabama Power Company–Tennessee Coal, Iron, and Railroad Company and Alabama Power Company–Tennessee Valley Authority tie-line wattmeter charts with Tennessee Coal, Iron, and Railroad Company load controller in service

A—Kilowatt loading on Gorgas–Wilson Dam 154-kv tie line

B—Kilowatt supply to Tennessee Coal, Iron, and Railroad Company by Alabama Power Company at Fairfield 110/44/6.6-kv step-down substation

C—Kilowatt loading on Tennessee Coal, Iron, and Railroad Company regulating generator

D—Kilowatt loading on hot-strip mill

The numbers 1 and 2 generators since the regulator was put in service are each set to carry a base load of approximately 15,000 kw. The number 3 generator, with the constant-steam-pressure regulator in operation, is loaded or unloaded in steps of 500 kw in accordance with the steam available to maintain the normal operating steam pressure of 335 pounds per square inch. This pressure control is not so sensitive as the new load control and in a measure acts to permit some of the steam to go to the load-controlled turbine generators. For instance, when the load controller functions to supply the additional steam for the numbers 1 and 2 generators, the steam pressure drops and the number-3-generator output, in accordance with the constant-steam-pressure control is reduced in steps of 500 kw to meet the new low steam pressure.

Maintaining the load controller in continuous service resolves itself into the problem of determining the drop in steam pressure permissible during the peak load period to permit the boilers to recover fully their initial steam pressure during the off-peak period of the mill.

A study of the test curves made December 9, 1944, with 13,000-pound slabs through the hot-strip mill, shows time of rolling is one minute with a peak of 19,000 kw and the time between slabs to mill is also one minute.

Number 1 generator only was under the control of the load controller during the test. The generator load was increased from base load of 14,000 kw with steam rate of 163,000 pounds per hour to peak of 23,000 kw with steam rate of 260,000 pounds per hour or an increase of 9,000 kw requiring additional steam at the rate of 97,000 pounds per hour. For one-minute duration 16,160 pounds of steam were supplied from the line storage and the flashing of water in the boilers. The steam pressure dropped from the normal of 335 pounds per square inch to the predetermined low level of 315 pounds per square inch or 20 pounds per square inch drop. Only once during the test of over two hours duration, and then when the last slab was being rolled, did the steam pressure drop below the predetermined low limit. The pressure bias control acted automatically to transfer that portion of the peak which the boilers could not supply to the Alabama Power Company's system.

Two alternate operations present themselves: to operate as per test with an occasional peak thrown on the Alabama Power Company's system, or to operate at a lower peak generation. The latter recourse has been followed, because the fluctuating demands on the boilers are re-

duced with less resultant disturbance to the equipment. The control now is set to pick up 6,000 kw generation to meet the mill peaks. This peak, requiring steam at rate of about 64,000 pounds per hour, is divided between the two turbo-generators, numbers 1 and 2. No difficulty has been experienced even when rolling smaller slabs with a shorter cycle of operation.

From the viewpoint of reducing the peak electric demands, the control functions as intended. The favorable results obtained are due in part to the fact that excess electric-generating capacity is available. The electric generators are operated at less than full output, owing to the limited boiler capacity and the limited blast-furnace gas available as fuel.

The control equipment and the generators are adequate to extend further the favorable results obtained, but, as emphasized in the foregoing, the limiting factor is the steam available for the peak electric generation. Further limiting factors and of prime concern to the plant operators are the effects of the modified operations on the steam-generating and consuming units.

With the peak control inactive, one of the noticeable features of the plant is the generally uniform water and steam conditions.

Had the generating plant of the Tennessee Coal, Iron, and Railroad Company been designed to carry the mill load under isolated operation, adequate provisions would have been made both in the steam-generating and consuming units. Of primary consideration would have been steam generators with larger steam drums and provisions for continuous fuel supply. Not designed for such requirements, the generating-plant equipment therefore has to be operated within its capabilities. Of chief concern to the operators is the possibility of water carry-over from the boilers to the steam users which, more than the ability of the boilers to recover steam pressure, is the limiting factor in determining the peak electric generation possible. This condition is aggravated owing to the varying blast-furnace fuel supply. During the periods of diminished blast-furnace gas there is a cooling of the boiler firebox with resultant effect on the boiler conditions. When this condition occurs concurrently with the increased cycle demand of steam, the effect is a widely varying boiler water level with increased possibility of carry-over in the steam. Greater demands are made on turbine valves and control equipment, and additional stresses are imposed on the turbine wheels, condenser tubes, boilers and their control equipment under peak load regulation. It is to be expected that repair and maintenance costs will be increased over the corresponding costs incurred under speed governing of local turbines in parallel with a large power system.

Various alternative methods of imposing peak loads on speed-governed prime movers operating in parallel with large power systems are discussed in the succeeding portion of this paper.

Various Means of Effecting Load Control of Turbine Generators*

A study of the conditions previously stated led to the formulation of the following specifications which a load control should meet in order to relieve the external power-supply system from peak loads of the hot-strip mill:

1. Given a variable supply of steam for the turbine generators operating in parallel with a large power system, one or each of two turbine generators should be so controlled that:

(*a*). A constant base load (10 to 100 per cent of generator rating) can be carried.

(*b*). A percentage (0 to 100 per cent of generator rating) of the variable load in the strip-mill circuit can be added to the base load.

(*c*). The base load is to be divided in any desired ratio between the two prime movers or all put on one.

(*d*). The percentage of variable load assigned to the prime movers is to be divided between the two prime movers in any desired proportions or all put on one prime mover.

(*e*). The base and variable loads placed on the prime movers are to be reduced from their maximums at maximum predetermined steam pressure as the pressure is reduced below maximum until both such loads are reduced to zero at a predetermined minimum operating pressure.

2. The variable load may have maximum conditions of:

Total load	20,000 kw
Rate of change—average over period of change	5,000 kw per second
Duration of peak	100 seconds

Various approaches to a set of conditions like these have been suggested. Some of these are discussed to bring out their features.

Scheduling of loads tends to reduce a tendency toward a cumulative demand and is quite effective in reducing demands which otherwise would extend over appreciable time periods. It requires suitable instruments, meters and communication or remote-control systems, and an operator to supply the necessary intelligence from a given set of facts or a control system to accomplish the same result automatically. From the standpoint of correcting instantaneous changes of load, it is an ineffective method as the procedure is too slow.

Numerous types of *anticipators* have been suggested, usually to be applied to an existing prime mover and its control. Normally the rate of response from the correcting element is excessively slow compared to the rate of load change under consideration. The initiating signals suggested include photoelectric cells, mechanical triggers, limit switches, and characteristics of certain initial steps of load changes.

Incomplete consideration of such anticipators sometimes indicates a relatively inexpensive arrangement with the thought projected that it could be put together in a repair shop. The suggestion, generally made, is that the anticipator operate the synchronizing motor of the prime mover.

Synchronizing-motor controls of turbine-generators usually have a rate of response of full load in about 30 seconds. To offset load changes of the type under discussion, one or more prime movers of at least a total size equal to the load change should be used. Therefore, the anticipator is expected to compensate for, say, 20,000-kw load changes which pass from minimum to maximum or vice versa at rates of 1,500 to 7,000 kw per second. Contrasted with the actual rate of load change, the anticipator and its auxiliaries can only count on a rate of response from the prime mover corresponding to its rating divided by 30 seconds, which, if it were a 20,000-kw unit, would respond at 667 kw per second excluding delays due to relaying and acceleration.

In many instances the incremental rates of load change when a slab or billet enters a stand are much faster than the average rates suggested.

Some mills use a scale breaker as the first stand in a mill. The scale breaker requires a relatively small amount of power, but sufficient when a slab enters it to cause a change in the series field current of the motor. Such a change might be used as a signal to trigger the operation of the synchronizing motor on the turbine generator. Several charts, showing in Figure 6 what might be accomplished if no time lags in the operation of the relaying were considered, illustrate the effect of

*Prepared by A. G. Darling.

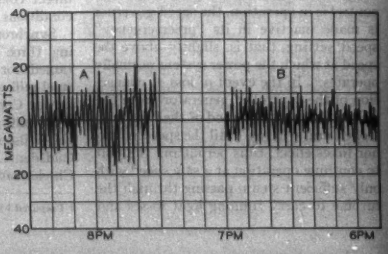

Figure 9. Gorgas-Wilson Dam 154-kv tie-line wattmeter chart showing the effect of the Tennessee Coal, Iron, and Railroad Company load controller on tie-line load swings

A—Load controller set on zero-load pickup

B—Load controller set on 50-per-cent-load pickup

such an anticipator working on a turbine generator having a rate of response by synchronizing motor of approximately 2,000 kw per second. It will be observed from the several charts that:

1. The turbine generator never follows the load changes.

2. There are as many peaks created on the system when the regulator is in operation as the mill creates plus two more in some instances.

3. There is an opportunity for actual power reversal in the interconnecting line between the mill and the power supply system.

Lastly, it also will be observed that, for each schedule of the mill, a change must be made in the timing elements introduced in the response element to correspond with the time and load increments created by the mill load. The mill operator is the best source of information for presetting such an anticipator, but, as his job is to get out production, it is likely that the responsibility for prescheduling will be placed on the prime-mover operator who is at a disadvantage from lack of first-hand information.

Fixed-value modifications to local prime-mover loadings also have been suggested which modifications would follow a preset schedule, depending upon the type of product to be rolled. An initiating signal of some type is required, and a set of timing devices which can be modified readily are also necessary. This method involves the same disadvantages as the anticipator method and, in addition, is not sensitive to what actually occurs in the mill.

By the time all the relays, control cable, and safety devices are considered, the cost of the anticipator and the accomplishment of fixed-value modifications is likely to approach that of a good load controller.

The type of control which was furnished and is described in detail in another Institute paper[1] meets the specifications, responds to the power in the circuit or circuits to be measured from which the variable loads emanate, and reinterprets not only the rates of change but also the value of the loads as they occur to an hydraulic servomotor capable of modifying the load on the turbine at the rate of 25 per cent of turbine rating per second. The electric circuits and servomotor arrangements are such that, when the load control is in operation, the speed governor is made inactive in its "preemergency" speed setting, that is, slightly above the speed at which the power system normally operates. In the event of loss of connection of the controlled generator from the electric system, the speed of the load-controlled unit will rise until the speed governor takes effect, thus permitting the unit to continue operation at a safe speed with only sufficient steam passing through the turbine to carry running light losses and keep the turbine at a reasonable temperature. The load controller holds the desired base load on the turbine generator and compares the measured consumption of the strip mill with the excess output of the generator over base load. If any difference occurs in these values, the load controller operates the turbine valves through a servomotor to rebalance the equation. Steam-pressure variations work through pressure-control elements to apportion the total generator output to the pressure variations between preset limits. Electric circuits are used to interpret the conditions in the strip-mill and generator circuits to the pilot motor of the hydraulic servomotor. Steam-pressure modifications are accomplished mechanically since the rates of change are slow. The connection from the servomotor cylinder to the turbine steam valves is the same as used for speed governor and is a chain of mechanical linkages, rack, pinions and cams.

Means of transferring the prime movers from speed governing to automatic load control as well as full adjustment of the base and percentage of the variable load to be assigned to the prime movers and adjustment of the pressure regulator are incorporated in the load-controller panel, so placing facilities and responsibility on one power-station control-board operator. The details of design and construction of the regulator are given in the companion paper.[1]

The effect of the regulator on the tie lines of the external power system is discussed in the last portion of this paper.

Effect of Load Regulation of Local Prime Movers on the Power System†

In order to check the over-all effect of the load control, an operating test of the controller action was made while the hot-strip mill was rolling a series of 56 13,000-pound slabs in quick succession at the rate of about 25 slabs per hour. The load controller was set to pick up 50 per cent of the load swing which, in the case of these slabs, amounted to approximately 10,000 kw. During this test the controller was cut in and out of service at 30-minute intervals in order to evaluate the effectiveness of the regulator by making a direct comparison of the two operating conditions.

Synchronized wattmeter charts, traveling three inches per minute, were obtained for the hot-strip-mill load, the steel-mill generator output, the Alabama Power Company's energy supply to the steel-mill load, and the load on the Gorgas–Wilson Dam 154-kv tie line. The Gadsden–Guntersville and Lindale–Chickamauga tie lines were open during the test to permit direct recording of the total tie-line load on a single chart. Representative load-test curves, replotted to a common kilowatt scale on rectangular co-ordinate paper, are shown in Figure 7 for the nonregulated condition, and in Figure 8 for the regulated condition. The effectiveness of the controller in suppressing the strip-mill load swings is clearly evident from a comparison of the two charts. The over-all effect as recorded on the tie-line wattmeter chart, traveling at the normal chart speed of three inches per hour, is shown in Figure 9, which indicates a considerable reduction in band width.

† Prepared by W. W. Eberhardt.

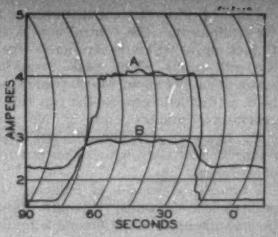

Figure 10. Timing chart of regulating generator and hot-strip-mill a-c secondary amperes

A—Hot-strip-mill current
B—Regulating generator current

As the effectiveness of the controller in offsetting fast load swings is dependent on close synchronism between the response variations in generator output and the strip-mill load-swing cycle, a further check was made to determine the over-all response time of the generator by feeding the strip-mill and generator a-c amperes directly into two high-speed ammeters having their charts driven from a common drive shaft. The results of this test are shown in Figure 10 and indicate an over-all response time of approximately two seconds.

In conclusion, it can be said that the controller performs as it was intended to function, with quick response, good stability, and negligible overshoot. Judging from the performance of the load controller when set for a 50-per-cent load pickup, it may be concluded safely that if the steam-plant boiler conditions would permit operation with a 100-per-cent pickup setting, the hot-strip-mill load swings would be completely eliminated from the Commonwealth and Southern–TVA tie lines.

Reference

1. Automatic Load Control for Turbine Generators, R. E. Crever, R. L. Jackson. AIEE Transactions, volume 64, 1945, September section, pages 656–60.

Dielectric Strength and Protection of Modern Dry-Type Air-Cooled Transformers

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TODAY there are in service over 1,000,000 kva of large dry-type air-cooled transformers, some in ratings as high as 4,000 kva and including the 15-kv voltage class. This wide acceptance in industry of the modern dry-type transformer and its continual growth, naturally has increased interest in its application and standardization. In a prior AIEE paper[1] the design characteristics, particularly with regard to thermal performance, have been discussed. The purpose of this paper is to review the development of the modern dry-type transformer, specifically with reference to its dielectric strength, and to present recommendations on impulse levels and methods of protection for applications which may be affected by lightning surges.

Application to Circuits Unexposed to Lightning

The development of the modern dry-type transformer was initiated in 1936, and at that time it was intended primarily for application to indoor and unexposed circuits where surge overvoltages are of internal origin. Until recently this has been the principal application for this type of apparatus. In this field of application surge overvoltages seldom will exceed three and one-half times the line-to-neutral crest voltage. Furthermore, the character of these surges is relatively slow compared to the abrupt effects resulting from impulse voltages. Figure 1, reproduced from reference 2, presents surge overvoltages that have been recorded in an extensive investigation on a 12-kv grounded-neutral system. A comprehensive survey of the subject is provided by the bibliography of reference 3. The data are typical of conditions encountered in these applications. On some ungrounded-neutral systems possibilities may exist of higher-surge overvoltages.

The low-frequency dielectric tests specified for dry-type transformers in American Standard *C57.1*, correspond to four or greater than four times the line-to-neutral operating voltage, and therefore in relation to the character of service the test has a practical significance. This and other requirements were taken fully into consideration in the design of dry-type transformers. In circuits unexposed to lightning no surge protection was deemed necessary, and none has been recommended. The experience with some 2,000 transformers in service amply bears out the adequacy of the design and the soundness of the practice recommended for these applications.

Impulse Insulation Levels

Though the greater part of the dry-type transformers built since 1936 has been applied to unexposed circuits, as in industrial services, it was recognized that even circuits otherwise unexposed may be subject to surges transferred through the medium of transformers from circuits exposed to lightning.[4] For this reason attention was given from the beginning to a balanced insulation design. Even more compelling have been the specific applications where practical considerations and economy dictated connecting dry-type transformers directly to incoming overhead lines exposed to lightning. Also, it will be well to note that the possibility of developing the dry-type transformer for application generally to distribution systems—exposed and unexposed—definitely has been in the foreground.

Let us consider the insulation design and construction of modern dry-type air-cooled transformers. The core and coil assembly is the conventional core form of construction as shown in Figure 2. For

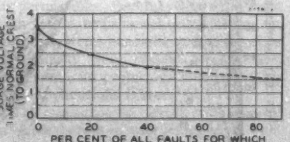

Figure 1. Surge voltages on 12-kv system[2]
Sphere-gap data 1932–38

Figure 2. View of core and coil assembly of dry-type air-cooled transformer

operating voltages up to 5,000 a cylindrical winding commonly is used, and above 5,000 and up to and including 15,000 the winding consists of a column of disk-type coils. The winding conductors are insulated with glass. The high- and low-voltage windings are arranged symmetrically about the core with the low-voltage cylindrical winding on the inside. Both the high- and low-voltage coils are wound and assembled separately on insulating barriers. First, the individual windings and then the assembled core and coils are treated with a high-temperature thermosetting varnish to add strength, to bond the conductor and coil insulation in place, and to give the assembly a smooth tough glossy finish which makes it highly resistant to moisture and dirt. The high-voltage coil column is supported at the top and bottom by large porcelain spacers. Porcelain spacers separate the high-voltage coils and space the coils from the high-voltage insulating barriers. Porcelain spacers also separate the low-voltage coils from the core assembly. The high- and low-voltage windings are centered and supported, so that an unimpeded air duct separates them and forms the major insulation of the transformer. The transformer leads, taps and terminals, and other live parts are supported on porcelain insulators.

The problem of securing a balanced insulation design in dry-type transformers fundamentally does not differ from the corresponding problem in other transformer apparatus. Figure 3 gives a typical impulse-voltage distribution, and Figure 4 illustrates a detailed study of the stresses developed throughout the high-voltage winding of a dry-type transformer. It is from these studies and the strength of the insulation parts that the design is

Paper 45-156, recommended by the AIEE committee on electric machinery for publication in AIEE TRANSACTIONS. Manuscript submitted June 21, 1945; made available for printing August 3, 1945.

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The authors acknowledge the assistance of their associates in securing the test data presented.

Table I. Typical Withstand Impulse Tests Applied to High-Voltage Terminals of Dry-Type Transformers

Transformer Rating	Impulse Wave*	Voltage, Kilovolts	Remarks
600 kva, 13,800–480 volts, Three phase, 60 cycles	$1^1/_2$x40-μs wave	50	With power-voltage excitation
500 kva, 13,800–480 volts, Three phase, 80 cycles	$1^1/_2$x40-μs wave	52	With power-voltage excitation
350 kva, 13,800–480 volts, Three phase, 60 cycle	$1^1/_2$x40-μs wave	51	With power-voltage excitation
	Steep-front wave, 0.20 μs	86	No power-voltage excitation
1,000 kva, 12,000–480 volts, Three phase, 60 cycles	$1^1/_2$x40-μs wave	54	No power-voltage excitation
	Chopped wave, two μs	62	No power-voltage excitation
200 kva, 2,400–480 volts Three phase, 60 cycles	$1^1/_2$x40-μs wave	25	With and without power-voltage excitation

*Impulse wave of positive polarity applied in all tests.

established. Modern dry-type transformers are of balanced-insulation design; that is, the coil, turn, and the other minor insulation are balanced with the major insulation so that the transformer can withstand an impulse wave of the voltage specified.

The impulse strength of transformers designed with balanced insulation is the product of the 60-cycle strength and the impulse ratio of the insulation. The dry-type transformer depends for its dielectric strength on air which has an impulse ratio of 1.1 to 1.3, depending upon the construction. Based on these fundamental considerations and the verification of designs from actual impulse tests as shown in Table I, the impulse levels in Table II have been established, and these have been proposed for standardization.

The impulse levels in Table II correspond to the $1^1/_2$x40-microsecond full wave. For purposes of standardization, in addition to the full wave, two chopped waves have been suggested to conform with present American Standards Association methods of testing. The chopped-wave voltage may well be 115 per cent of the full wave. Waves of positive polarity generally are more effective for testing dry-type apparatus and therefore are recommended.

Table I illustrates typical tests that

Table II. Impulse Insulation Levels of Dry-Type Transformers

Insulation Class, Kilovolts	Low-Frequency, Dielectric Tests, Kilovolts Rms	Impulse Levels $1^1/_2$x40-μs Wave, Kilovolts Crest
1.2	4	10
2.5	10	20
5.0	12	35
8.66	19	35
15.0	31	50

have been applied to dry-type transformers, ranging from full-wave to chopped-wave to front-of-wave impulses. These are designated as withstand tests, for they represent test voltages at which the same relative margin is maintained with respect to ultimate strength as for the full wave at impulse level. Figure 5 illustrates corresponding oscillograms. These data demonstrate the rising volt–time characteristic of the insulation, the significance of which will become more apparent under the discussion of protection. A second point of practical interest to note is the ability of these modern dry-type transformers to withstand repeated impulses without any sign of deterioration, even when carried to the point of flashover. For instance, in a series of tests applied to 13,800-volt windings of the 350-kva transformer referred to in Table I, this transformer was subjected to a combined total of 100 impulses divided between full wave, chopped wave, and front of wave. Some of these tests were carried to the point of flashover of the insulation without causing any ill effect to the transformer. In the impulse tests to failure, flashover usually occurred across porcelain insulators supporting the leads or from lead terminals to ground, not affecting the more vital parts of the transformer.

Protection Against Lightning Surges

When dry-type transformers are applied to circuits exposed to lightning surges, the impulse characteristics of the apparatus in relation to the protective devices available and to the degree of protection expected need to be considered. In such cases only lightning arresters having a low protective ratio are recommended, and for effective protection they should be connected at the terminals of the transformer as shown in Figure 6. These arresters are the types that have been developed for the protection of rotating machines and applied to motors and generators for many years. They are available in station and line types. In the application to dry-type transformers, only the line type is justified economically in most cases. This arrester is known as the type *RM*, indicating its application to rotating machinery. The characteristics of the arresters are given in Table III, which summarizes data from recent tests on commercial arresters.

Verification tests have been conducted on these lightning arresters in combination with transformers. In a series of tests the complete transformer assembly plus the arrester were excited at normal power voltage from a 2,000-kva power supply, much in the manner the installation would operate in service. The impulses applied were synchronized to the crest of the 60-cycle voltage as in the standard impulse tests. For instance, the oscillograms *A* and *B* in Figure 7 demonstrate the impulse voltages at the 13,800-

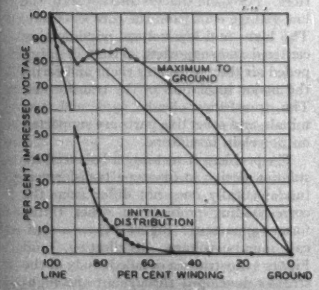


Figure 3. Voltage distribution in 13,750-volt winding, 1.6x37-microsecond wave applied

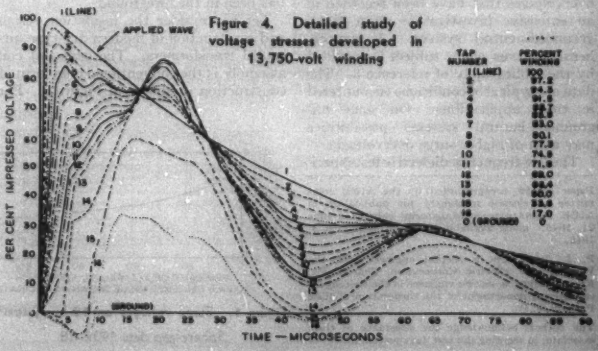


Figure 4. Detailed study of voltage stresses developed in 13,750-volt winding

Table III. Performance Characteristics of Type-*RM* Arresters*

Arrester Rating, Kilovolts Rms	Phase-to-Phase Circuit Voltage Rating		60-Cycle Gap Breakdown, Kilovolts Rms	Impulse Breakdown in Kilovolts Crest		Discharge-Voltage Kilovolt Crest on 10x20-μs Currents	
	Ungrounded Neutral System	Solidly Grounded Neutral System		Front of Wave**	1½×40-μs Wave	1,500 Amperes	3,000 Amperes
3	2,400	4,160	6	13	9	9	10
6	4,800	7,200	12	24	18	18	20
9	7,300	11,500	18	32	27	27	30
12		13,800	24	40	36	36	40
15	13,800		30	48	45	45	50

*These arresters are special and should not be used interchangeably with standard distribution arresters.

**Test wave as recommended in AIEE Standard 28 for standard valve-type arresters.

volt terminal of a 350-kva transformer without protection and with a 15-kv *RM* arrester connected from terminal to case respectively. In another series of tests the voltage generated and applied was increased to several times the full-wave insulation level of the terminal. For instance, oscillogram *C* of Figure 7 is the generated voltage applied on repeated tests (ten) to one of the 13,800-volt terminals of the 350-kva transformer with a 15-kv *RM* arrester connected from the terminal to case. In effect this test corresponds to an incoming surge on a well-insulated overhead line having a surge impedance of 450 ohms, since the series resistance in the impulse generator was of this amount. As shown by oscillogram *D*, the voltage at the transformer is limited by the arrester. In this particular test lengths of leads included in the protective circuit produced an additional momentary voltage above the arrester characteristic, as shown by the initial instantaneous peak of 79 kv. In no instance during these tests was any ill effect whatsoever observed on the transformer insulation so that the conclusion definitely is drawn that even under these severe lightning surge conditions a good degree of protection can be provided to dry-type transformers with *RM* arresters, provided they are properly applied.

The rating of a lightning arrester for a particular installation is determined by the maximum dynamic voltage from line to ground. With solidly grounded-neutral systems the arrester rating can be less than line-to-line circuit voltage. Usually the next lower rating may be applied. For instance, on a 13.8-kv system with solidly grounded neutral, a 12-kv arrester may be applied with the advantage of an additional 20-per-cent increase in the margin of protection and at lower cost. Likewise, the availability of *RM* arresters at intermediate ratings as 4.5 kv and 7.5 kv should contribute to better protection in applications at the lower voltages.

Classes of Application and Protective Methods

In all problems of protection the question is to determine first, the extent apparatus may be endangered, and, second, whether the relative risk incurred, weighed against the importance of the installation and the cost of damage, warrants protective equipment. Where protection is required, the method should be effective and in keeping with economy. Let us consider the various possible applications and protective methods for modern dry-type transformers.

The extent dry-type transformers may be subject to lightning surges depends entirely upon the degree of exposure of the circuits to which they connect. For convenience, these are classified as follows:

1. Unexposed.
2. Quasiexposed.
3. Exposed.
4. Highly exposed.

The protective methods recommended for these various applications are outlined schematically in Figure 8.

The unexposed circuit is one on which lightning surges practically are nonexistent. That is, the circuit is either disassociated from lightning surges or only remotely coupled electrically to their source. Most industrial applications indoors, applications in mines and to underground cable systems, and many others come within this classification. As stated previously, system overvoltages on distribution and network circuits as commonly operated in this country seldom exceed three to four times line-to-ground normal crest voltage. On systems with the neutral isolated, conditions may develop resulting in somewhat higher-surge overvoltages. Considering that the strength of dry-type transformers to these surges is comparable to the impulse strength (Table II), system overvoltages five to six times, and higher for the lower classes, are permissible. Several years' experience from many transformer installations on various systems has indicated no instance of difficulty from system overvoltages. In general, no protection is required for these applications (Figure 8A).

The quasiexposed circuit would be one in which there is an intervening bank of oil-immersed transformers between the dry-type transformer and the exposed or highly exposed circuit, as shown in B of Figure 8. When a dry-type transformer is connected in the manner indicated, it is in general not necessary to use lightning-arrester protection at the transformer, provided the intervening transformers are protected properly on the exposed side.

Figure 5. Typical full-wave and front-of-wave impulse voltages applied to dry-type air-cooled transformers, 15-kv insulation class

Oscillograms from tests on a 350-kva 13,800–480-volt three-phase 60-cycle transformer

Figure 6. Built-in lightning-arrester protection in dry-type air-cooled transformer

It is assumed that the secondary circuit from the intervening transformers is unexposed; for instance, that it extends to the supply centers as a cable system or it enters directly into an industrial establishment. Should the dry-type transformer be connected closely adjacent to the secondary terminals of the intervening transformer and it alone become the entire load, lightning protection of the dry-type transformer would be necessary.[4]

Exposed and highly exposed circuits are treated here as one. They differ in degree as to the frequency of occurrence and intensity of lightning surges to which each are subject. The exposed circuit would be one situated in urban districts or located such that there is some shielding from surrounding buildings or objects. It may have an impulse level of the order of 100 to 150 kv. The highly exposed circuit is one which is insulated with wood construction throughout, that is, wood poles, wood crossarms, wood braces, and so forth, and located in a territory which has a high lightning occurrence and intensity. Such a line would have an impulse level of 300 kv or greater and impulse voltages of this order actually may build up on it. In either case the incoming line connects directly to the dry-type transformers.

In these applications standard expulsion or valve-type distribution arresters are recommended on the incoming lines, in addition to the low-ratio arresters at the terminals of the transformer, preferably 500 to 1,000 feet from the transformer, as shown in C of Figure 8. The addition of the protective device on the line contributes to the over-all scheme of protection in that it takes the brunt of incoming high-current surges and permits the arrester at the transformer to function within its rating and provide a higher degree of protection to the transformer. Capacitors such as specified for rotating machines are not required. On urban circuits where "shielding" of the circuit is known to reduce the frequency and intensity of surges to a fractional part of the amount encountered in rural exposed circuits, the protective device on the line may be omitted. On highly exposed circuits some risk of direct strokes to the 500- or 1,000-foot section of line between the line arrester and the transformer may be present. This probability must be recognized, although it is fairly small. In general an overhead ground wire to shield the 500- to 1,000-foot end section of the line would not be justified. It is recognized that the special station-type arrester used for rotating-machine protection provides a somewhat greater margin of safety, because in the rare event of a stroke to the section of line adjacent to the transformer the station arrester gives added protection because of its greater current-discharge capacity and somewhat better protective level. For certain large and important installations its use may be justified, but for the general application the type *RM* arrester is the most practical.

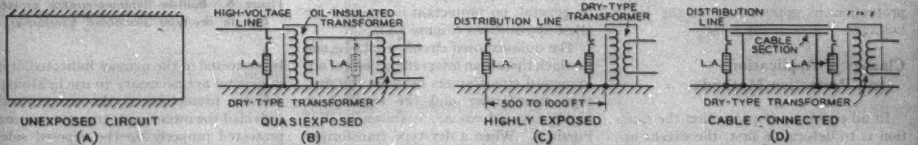
Figure 7. Impulse tests on transformer provided with lightning-arrester protection

350-kva 13,800–480-volt three-phase 60-cycle transformer and 15-kv *RM* arrester

Up to the present specific applications of dry-type transformers to exposed circuits have been almost entirely as shown schematically in D of Figure 8. The principal reason for this arrangement is that it lends itself quite conveniently to the entire installation. This commonly consists of the incoming distribution line, usually of wood construction, terminating outside the industrial establishment or adjacent to the site of power supply, the circuit continuing to the transformer proper as a cable section up to several hundred feet long. This arrangement has inherent merits also from a protection standpoint. As indicated, *RM* line-type arresters at the transformer combined with standard expulsion or valve-type distribution arresters applied to the cable pothead at the line end will provide a high degree of protection in this type of installation. At the line end the arrester ground terminals should connect directly to the cable sheath and to ground through a ground wire. The arresters at the transformer preferably should be built in, as shown in Figure 6, thus securing minimum length of arrester leads from the terminals to case and therefore the best over-all protection; this combination has other constructional and safety advantages. On distribution circuits which operate under conditions of low exposure, the arrester at the line end of the cable may be dispensed with.

The foregoing recommendations are based on fundamental engineering considerations. In addition they have been corroborated by test. For instance, tests were conducted on a test setup corresponding to the arrangement of Figure 8D, with a lead-sheath cable 250 feet in length. One end of the cable was connected to the high-voltage terminal (high-voltage insulation of 15-kv class) of a 1,000-kva air-cooled dry-type transformer, the other end to the impulse generator. In these tests a 15-kv *RM* line-type arrester was applied at the transformer, backed up by a line-type 15-kv arrester at the line end of the cable, in the manner recommended for highly exposed circuits. The series resistance of the generator was approximately 450 ohms for generated voltages above 200 kv and considerably less for other voltages. The term "generated voltage" as used here simply means the voltage that the impulse generator would have developed with no connection made to the cable. It represents, so to speak, the impulse applied to the line terminal of the cable, modified and limited, of course, by the circuit and the arresters. The front of the generated voltage in these tests was close to one microsecond. The duration of the wave to half-crest value as

Figure 8. Classes of application and protective methods



Constant-Speed Drives for Aircraft Alternators

C. J. BREITWIESER
MEMBER AIEE

IN LARGE MILITARY AIRCRAFT the demand upon the electric system has been increasing exponentially. At the start of the war, 50-ampere generators were considered ample; this rating soon jumped to 100, and now 200-ampere generators on our four-engine bombers are inadequate. As the limits of power output are reached, the necessity for satisfactory parallel operation and equality of division of the load becomes extremely important.

During ground operations, the main engines operate at low speed, and the battery is called upon to supply essential loads since at low speeds the generators are not supplying power. Before a flight, the crew frequently check the operation of turrets and other equipment and quickly discharge the low-capacity storage batteries of the airplane.

In this is seen the shaping of a demand for a more constant-speed type of drive for generators for airplanes. The problem of paralleling generators and obtaining equality of load distribution is greatly reduced if the generators can all be driven at a constant speed, and also power for ground operation or low engine speed would be provided automatically.

Paper 45-163, recommended by the AIEE committee on air transportation for publication in AIEE TRANSACTIONS. Manuscript submitted July 23, 1945; made available for printing August 17, 1945.

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As the demands for more electric power and transmission distances have increased, it has become apparent that the present 30-volt d-c system is no longer adequate. In a current design of a large airplane, the conductor weight for a 30-volt system would be in excess of a ton and a half; whereas, if the voltage were increased to 250 volts, the weight would be reduced to approximately 250 pounds.

Contrary to a popular misconception, weight is just as important, if not more so, in large airplanes as in small. There is a tendency, in large airplanes, for designers to be more extravagant with weight and size; and, if this tendency is not curtailed and an effort made to use the most advanced metallurgy and efficient structural design, progress will be at a standstill, for advancement cannot be made by aerodynamic efficiency alone.

The demand for increased range also has emphasized the importance of weight in aircraft. It is not at all unusual to find present-day airplanes carrying once again their own weight in fuel and oil.

In other words, every pound that could be saved on the airplane represents two pounds' reduction in the gross weight of a long-range airplane.

Every ounce on an airplane must pay for itself. In military aircraft an increase in weight must provide either an important operational or tactical function, structural advantage, increased reliability, or decreased vulnerability. In commercial operation, extra pounds mean reduced pay-load and revenue. The cost of extra pounds has been evaluated quite accurately in dollars and cents by the commercial lines. Estimations range from $500 to $1,500 a pound. If dollars and cents talk, this should be a mighty strong talking point for the reduction in weight.

Constant-Frequency A-C System for Large Aircraft

Weight saving cannot be made, however, at the sacrifice of reliability. The "in-the-air" reliability of aircraft components must be very high. High-altitude flying conditions place additional burdens on equipment. The wide ranges of ambient temperatures encountered with military aircraft also add to the difficulties.

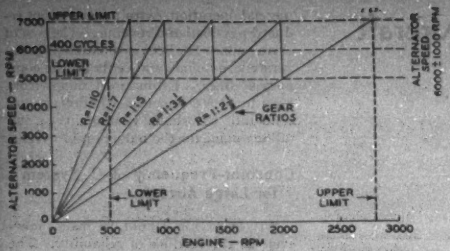
After careful study of the particular problems of some large-size long-range airplane designs, it was concluded that a high-voltage high-frequency three-phase a-c system would result in improved altitude performance and a weight saving. A voltage of around 200 volts permits a large reduction in conductor weight, and the reliability of a three-phase induction motor is unsurpassed by any other type of motor. Other factors such as circuit-breaker and switch design, and ease of voltage transformation, also influenced the choice of alternating current.

A variable-frequency variable-voltage system was ruled out because of the demands of many existing accessories which have been designed for constant-voltage supply. Because of the favorable speed ranges, light motor and transformer weights, and the possibility of direct application to many existing pieces of equipment, a frequency of 400 cycles was chosen.

This question then presented itself: How would the alternator be driven? A small auxiliary power plant was an obvious solution. However, upon more careful consideration, it is apparent that the installation would involve an excessive amount of weight. The auxiliary power plant must be pressurized for high-altitude operation, heated for the extreme cold of the upper atmosphere, and cooled for ground operation. The specific fuel consumption of the auxiliary power plant is greater than that of the main engines, and also prime mover capacity is, in effect, duplicated, resulting in a weight increase. A study on a large airplane indicated that on a long-range mission the use of an auxiliary power plant would add 1,500 pounds to the gross weight of the airplane. It was, therefore, apparent that the main engines should be used as a source of prime power for the electric system.

Requirements for a Constant-Speed Drive

With a decision to use the main engines as a source of driving power for the alter-



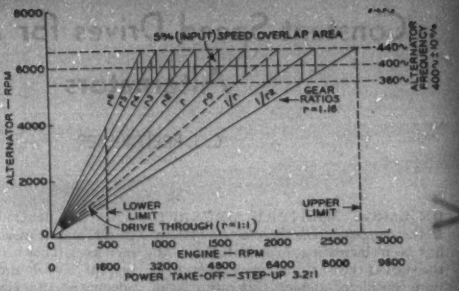


Figure 1. Alternator speed versus engine speed for a five-speed gearbox

Gear ratios chosen to provide an alternator speed 6,000 ± 1,000 rpm throughout operating range of the engine

Figure 2. Alternator speed versus engine speed for a multiple staging of constant-ratio gear sets to provide a frequency regulation of ± 10 per cent with a 5-per-cent speed overlap for clutching

nators, the necessity for some form of a variable-ratio coupling becomes apparent. An aircraft engine may vary from 500 rpm at idling to 3,000 rpm at military power. For a fixed-frequency system, the alternator requires a constant driving speed at all times. Since the power output of an induction motor is inversely proportional to the square of the frequency, it is desirable to maintain essentially constant frequency. If the system frequency is 400 cycles and an eight-pole alternator is used, the variable-ratio drive would be required to supply a constant 6,000-rpm output for input speeds ranging from 500 to 3,000 rpm. This is a ratio variation of 12:1 at low speed, to 2:1 at high speed.

The auxiliary power requirements of some of the new heavy bombers are upwards of 50 horsepower. Ordinarily an alternator must be capable of supplying a 100-per-cent overload for short-time periods. The variable-ratio drive, therefore, must be capable of supplying 50 horsepower continuously and 100 horsepower for short intervals.

This must be accomplished for a minimum of weight and mechanical complexity. If the device becomes too heavy and complex, it would lose its advantage over a direct-driven auxiliary power plant.

Finite-Ratio Versus Infinite-Ratio Drive

A selective fixed-ratio device could be used to maintain the alternator within a certain specific speed range. For example, a multiple-stage gearbox which would provide selective ratios of 10, 7, 5, $3^1/_2$, and $2^1/_2$ to 1 would maintain the alternator at speeds which would vary roughly 1,000 rpm above and below the required 6,000 rpm as the engine speed changed from 500 to 3,000 rpm (Figure 1). The speed variation would not be too objectionable so far as most of the motor applications were concerned, but a variation of plus or minus 1,000 rpm would result in a torque variation (assuming the voltage was held constant) of approximately 2:1 which would be objectionable.

Another disadvantage of a finite ratio is the difficulty which would be encountered in the parallel operation of alternators. Unless some auxiliary flexible coupling were used, it would not be possible to maintain parallel operation of the alternators.

This flexible coupling would have to provide for a speed differential of approximately 1,000 rpm if the afore-mentioned ratios were used in the fixed-ratio drive. A certain amount of droop would be desirable. These characteristics could be provided by a fluid coupling, but would add weight to the drive and reduce efficiency.

A planetary gear set can be switched from one ratio to another by means of electrically actuated clutches without too much difficulty. The clutches may be energized by suitable contacts on the governor. Overlap of the ratio-change contacts must be provided to eliminate chattering or hunting when the speed is in the vicinity of the ratio-change values.

The design and operation of an automatic ratio selector may be simplified considerably by using a constant ratio between successive gear sets. The ratios already indicated are not related by any common ratio. A separate gear set would have to be used for each ratio which has no common factor. A factorial relationship between gear sets permits various combinations of gear groups to be used to produce the desired over-all ratios.

The chart in Figure 2 shows the variation of alternator speed over the range in engine speed. The multispeed gearbox is connected to an engine-power take-off which has a step-up ratio of 3.2:1. The multistage gearing consists of two step-down ratios of $1/r$ and $1/r^3$, a drive-through or 1:1 ratio, and six step-up ratios of r, r^2, r^3, r^4, r^5, r^6. By the use of this common ratio, r, considerable simplification in the multistage gear can be accomplished by using various combinations of the factorially related gear sets to obtain the desired over-all ratios.

The arrangement shown in Figure 2 will provide an alternator speed range such that the frequency will vary only ± 10 per cent from the desired 400 cycles.

An overlap of five per cent of the input speed is provided to eliminate sporadic operation of the automatic ratio selector. This selector may be coupled to either the input or output shaft. The fixed percentage of input speed for overlap and sequential operation of the gear sets can probably best be provided for by a control governor attached to the input shaft. An overspeed protective governor would preferably be attached to the alternator shaft.

Chrysler Corporation photo

Figure 3. An infinite-ratio mechanical-drive coupled to an experimental 37.5-kva aircraft alternator

Infinite-Ratio Coupling

For parallel operation of alternators, the multistage gearbox would not be suitable unless some auxiliary flexible coupling, capable of adjusting the speed over a range of ten per cent, were used. This would not be entirely satisfactory, for there may be times when the main engines are operating in the same speed range. This coupling also would have to be capable of acting very rapidly, for, during the intervals of gear-set changes, large differential in output speeds would arise.

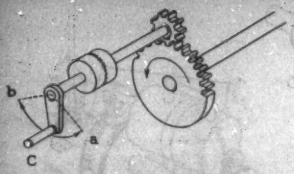


Figure 4. A spur gear driven by an oscillating small pinion gear

The pinion is connected by means of a freewheeling unit to a crank *C* which rocks from *a* to *b*

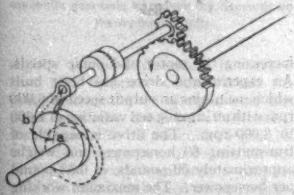


Figure 5. A cam and follower have been substituted for the crank

The same oscillating motion is provided

A more satisfactory drive would be one in which the ratio could be varied infinitely and rapidly. A fluid coupling of the hydraulic clutch would function, but its efficiency is so low over the required speed range that it is impractical to use.

The same criticism applies to any other type of drive which utilizes a slipping element for speed change, be it hydraulic, mechanical, or electrical. Slip, regardless of the type of element is manifest in energy loss and is wasteful of power.

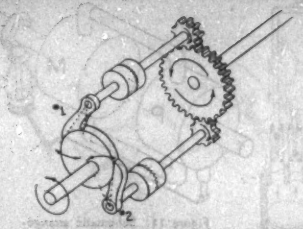


Figure 6. An additional pinion, freewheeling unit, and cam follower have been added to double the number of impulses from the rotating cam

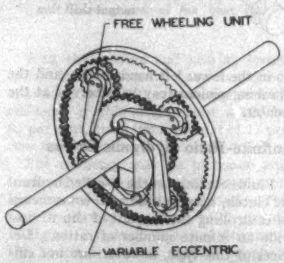


Figure 7. A four-pinion assembly with freewheeling units integral with the pinion gears and a variable eccentric cam on the input shaft

In an airplane, efficiency is important from two standpoints:

(*a*). The amount of fuel which must be carried to furnish the auxiliary power.

(*b*). Cooling provisions which must be provided for the drive.

Added fuel increases the gross weight, and cooling provisions usually add to both weight and drag.

Two infinite-ratio coupling systems have been developed, which embody positive translations. One system is strictly mechanical, and the other is hydraulic. Because these systems do not depend upon slip, their efficiency is high. In general, it is easier to govern a slip device than a variable positive-translation device. This has been found to be true in the case of these devices. The governing has proved a problem, and it has been difficult to attain the desired rapidity of ratio change necessary to maintain constant-output speed throughout the range of speeds and accelerations of the engines.

Infinite-Ratio Mechanical Drive

A unique and efficient mechanical system has been developed by the Chrysler Corporation for providing continuously variable-ratio coupling (A drive attached to a 37.5-kva alternator is shown in Figure 3).

The device operates in the following manner:

In Figure 4 the output shaft is driven by means of the small pinion and spur gear. Oscillation of crank *C* from positions *a* to *b* transmits, through the freewheeling ratchet, intermittent rotation of the pinion gear in a clockwise direction. The pinion gear drives the output spur gear, revolving the output shaft in a counterclockwise direction.

In Figure 5 the crank has been replaced by a shoe riding on a cam. The cam is attached to the input shaft, and, as the input shaft revolves, the shoe will oscillate from *a* to *b*, driving the pinion and spur gear in a manner similar to the oscillating crank arrangement of Figure 4.

The output shaft will receive an impulse of acceleration each time the shoe is displaced from *a* to *b*. An additional impulse may be added by arranging another shoe and freewheeling pinion gear diametrically opposite shoe 1, as indicated in Figure 6.

Additional impulses likewise may be given the output spur gear by the additional shoe and pinion gear assemblies. The magnitude of the impulse is determined by the angular acceleration and displacement of the shoe, which is dependent

Figure 8. Components of a pinion gear and freewheeling assembly from the infinite-ratio mechanical drive

Chrysler Corporation photo

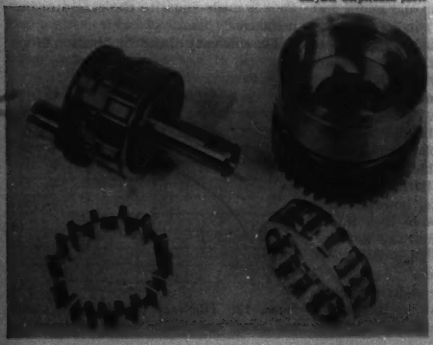


Figure 9. Assembly showing the pinion gears and one of the cam followers

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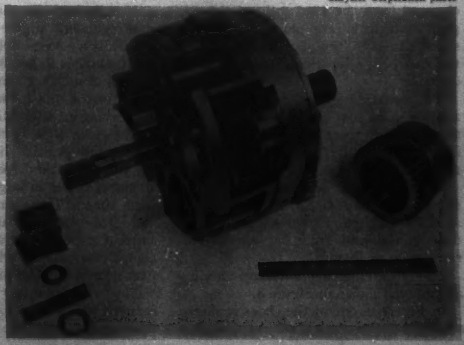

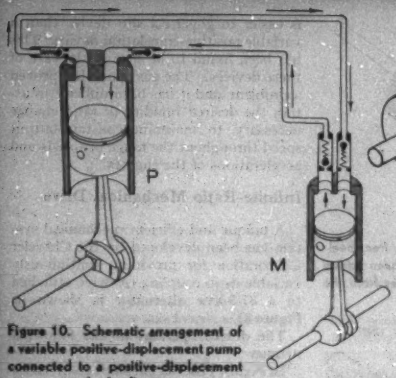

Figure 10. Schematic arrangement of a variable positive-displacement pump connected to a positive-displacement hydraulic motor

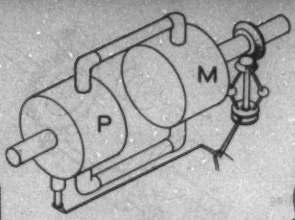

Figure 11. Schematic arrangement of a hydraulic-pump and motor combination with a governor controlling the pump displacement attached to the output shaft

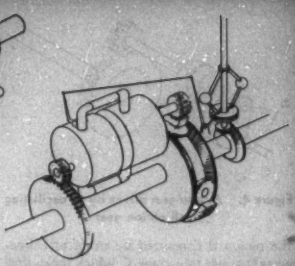

Figure 12. Schematic arrangement of a pump and motor combination utilizing a differential gear to limit the demands upon the hydraulic link

upon the speed and eccentricity of the cam.

In Figure 7 an arrangement is shown with four pinion units with concentric freewheeling units coupled by means of connecting rods to shoes which slide on the driving cam. In this arrangement the pinions are planets in a planetary gear system. As the cam revolves, these planet pinions impart driving impulses to the driven spur gear in the same manner as in Figure 6.

The ring gear is coupled by means of reduction gearing (not shown in the figure) to the drive shaft and drives the output shaft directly, since the planet pinions are locked effectively by the ratchet action of the freewheeling elements.

Since the ring gear is geared down from the drive shaft, the cam will revolve faster than the ring gear and will impart accelerating impulses to the planet pinions proportionate to the amount of eccentricity, which will add to the speed of the driven spur.

The acceleration impulses are proportional to the eccentricity of the cam. The additive speed differential may be varied by changing the amount of eccentricity. Therefore, the ratio of the drive can be changed from the fixed ratio of the ring gear to the fixed ratio plus the additional speed added by the planet pinions when the cam is in a position of maximum eccentricity.

The variation of cam eccentricity from zero to maximum may be perfectly continuous and, therefore, will provide an infinite number of ratios between the aforementioned limits.

This illustrates in principle the drive shown in Figures 3, 8, and 9; however, actual construction details of the drive differ considerably from the simplified arrangement of Figure 7.

One of the crank arms and freewheeling assembly is shown in Figure 8.

In Figure 9, one of the shoes is shown attached to the crank arm. A single shoe is in the lower left-hand corner, and the meshing pinions may be observed at the center.

Infinite-Ratio Hydraulic Drives

Fluid couplings, or the so-called hydraulic clutch, may be used with some means of controlling the amount of slip to provide an infinite number of ratios. Devices of this type, however, are not efficient over a very wide range in speed.

Drives have been developed which embody essentially the same basic principle as the previously described mechanical system and are quite efficient throughout a wide speed range. These drives are direct-coupled and depend upon a controllable positive displacement.

For example, Figure 10 shows a simplified arrangement of this type of drive. The unit consists of positive displacement motor M, coupled to a positive displacement pump P, in which the displacement may be controlled.

By varying the eccentricity of the drive cam, the volume of the fluid which is pumped each stroke is changed, and accordingly the ratio between the input shaft and output is changed. The ratio is infinitely variable over a large range of speeds.

Usually both the pump and motor are multicylinder. Figure 11 indicates schematically a governor placed on the output shaft which is linked to the displacement control in such a manner that the output speed of the unit is maintained constant for driving an alternator.

The use of a variable-displacement pump and positive-displacement motor for variable-ratio drives has been applied to turret drives in large battleships for a long time. These units, however, are very heavy and, because of their intermittent type of operation, are not designed for particularly high efficiency over a large range of ratios.

The weight of this type of drive may be reduced by two methods: by increasing the working hydraulic pressures, and by increasing the motor and pump speeds. An experimental drive has been built which maintains an output speed of 6,000 rpm with an input-speed variation of 1,000 to 3,000 rpm. The drive is capable of transmitting 60 horsepower and weighs approximately 50 pounds, or 0.83 pound per horsepower. The maximum working pressure is 4,500 pounds per square inch, and the motor pump speeds are on the order of 18,000 rpm. Even though the unit is extremely light and of high speed, the efficiency is surprisingly good, varying from about 70 per cent at the worst condition to 83 per cent at maximum.

Methods For Improving Efficiency

A method for improving the efficiency of a variable-ratio drive of this type is shown in Figure 12. The method is based upon the fact that the efficiency of a variable-displacement pump and constant positive-displacement pump is a maximum for one particular flow. This is a condition in which the reflected mechanical impedance of the motor load most nearly matches the effective internal impedance of the pump and the associated hydraulic circuit. This is analogous to the conditions for transferring maximum power in an electric circuit when the load impedance is made equal to the generator impedance.

The efficiency of the combination drops

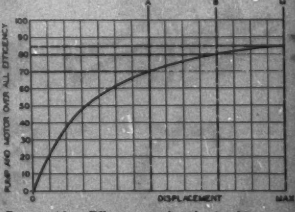

Figure 13. Efficiency of a hydraulic pump and motor combination versus displacement

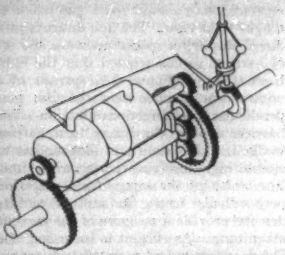

Figure 14. Schematic arrangement for improving the efficiency of a drive by the use of an epicyclic gear train to reduce the demands on the hydraulic units

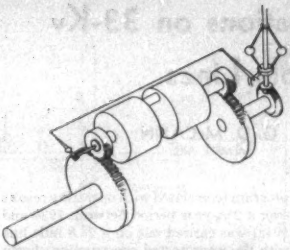

Figure 15. A hydraulic "differential" in which the pump and motor units revolve as a unit forming part of the gear set

slightly as the displacement is changed from this optimum value. When the pump and motor are of equal size, this point is usually the point of maximum displacement for the pump. See Figure 10.

In the arrangement of Figure 12, the pump and motor combination supplies only the differential speed which is necessary to bring the output shaft up to the desired constant speed. For example, if the drive-shaft speed varies from 2,000 to 6,000 rpm, and it is desired to maintain 6,000 rpm on the alternator, it will be necessary for the hydraulic unit to supply, through the differential gear, an additional 4,000 rpm to the alternator when the input is 2,000.

This would be the point of maximum demand on the hydraulic unit and would require the maximum displacement of the pump which occurs at maximum efficiency.

As the driver speed increases, the demands on the hydraulic units become less and less until an end point is reached when the driver is revolving at 6,000 rpm and there is zero demand from the differential gear. The efficiency falls off as zero is approached (see Figure 13), but, as the unit is supplying proportionately less power (the major portion of the power being supplied directly through the differential gear), the net over-all efficiency will remain high since it is a combination of the mechanical and hydraulic efficiency.

For purposes of rough comparison, assume a median efficiency of 70 per cent for a straight hydraulically coupled system, as indicated in Figure 13, and compare it with the foregoing. If one neglects the bearing and gear efficiency, it may be assumed roughly that the power demands will be divided between the hydraulic and mechanical sections proportional to the speed requirements.

With the driver varying from 2,000 to 6,000 rpm, the driver median speed is 4,000 rpm, and the speed demand on the hydraulic unit is 2,000 rpm. If one assumes the same median over-all hydraulic efficiency as above 70 per cent, the over-all efficiency of this arrangement is then 90 per cent.

With the gearing and bearing losses, which had previously been neglected, approximated as 10 per cent, the over-all efficiency of this arrangement would be 81 per cent, or an improvement of 11 per cent over the straight hydraulic drive.

The efficiency may be increased still further by using a pump and motor combination which can be reversed. The same type of arrangement, as illustrated in Figure 12, is used. In this arrangement the hydraulic unit is used to supply a differential speed above and below a median speed of the driver.

If the drive shaft had the same speed range as before (2,000 to 6,000 rpm), an epicyclic differential-gear set could be substituted for the conventional differential shown in Figure 14. The epicyclic gear set would incorporate a step-up to the output shaft of $1^1/_2$:1 such that the speed range of the output shaft would be 3,000 to 9,000 rpm if no differential-speed increment was supplied through the hydraulic unit.

At the median speed of the driver, 4,000 rpm, there would be no differential-speed demand as the output shaft would be revolving at the required 6,000 rpm. For input speed below this value, (2,000 to 4,000 rpm), the hydraulic unit would act as an overdrive and supply the necessary differential speed to bring the output up to 6,000 rpm (2,000 to 0 times the $1^1/_2$:1 ratio of the epicyclic gear). For the driver speed range of 4,000 to 6,000, the hydraulic unit would act as an underdrive, supplying the necessary negative differential to bring the speed down to the required 6,000 rpm.

The absolute speed range of the hydraulic unit, in this manner, is limited to 0 to 2,000 rpm, rather than the range of 0 to 4,000 rpm which was required in the previous case.

If one considers a hydraulic unit similar to the previous one, the efficiency at the median speed will be of the order as indicated by the dashed line *B* on Figure 13, or 80 per cent, which is a 10-per-cent improvement over the other arrangement. If the efficiency is calculated on the same basis as before, the over-all efficiency of the unit, with gearing and bearing losses neglected, would be approximately 96.6 per cent and, if a 10-per-cent loss in these two items were assumed, the total over-all efficiency would be 87 per cent, or a 6-per-cent improvement over the previous arrangement and a 17-per-cent improvement over the direct-coupled hydraulic arrangement shown in Figure 11.

The same results could be accomplished if the gear ratio of the power take-off were increased so as to provide a 3,000-to-9,000-rpm range of the driven shaft and a conventional differential gear were used instead of the epicyclic set.

Another arrangement which utilizes the same principle of overdrive and underdrive for increasing efficiency by limiting the speed range of the hydraulic units is shown in Figure 15. This arrangement does not use a differential gear, but the differential speed is supplied in a similar manner by the hydraulic unit.

For this method, the hydraulic pump and motor must be capable of rotating as a unit (zero displacement of hydraulic fluid) and also rotating in either direction relative to each other.

The pump is likewise a variable-displacement unit; and the motor, a con-

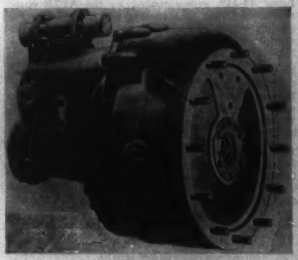

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Figure 16. A hydraulic infinite-ratio drive for a 40-kva aircraft alternator

Army standard spline and pad for 208/110-volt 400-cycle alternators

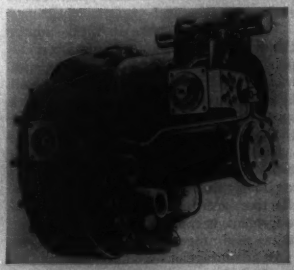

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Figure 17. Hydraulic infinite-ratio drive showing pad for connection of drive shaft to airplane main engine

Lightning Investigations on 33-Kv Wood-Pole Lines

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IN RECENT YEARS the importance of providing reliable service over lines in the transmission class of 22 to 44 kv has greatly increased. However, little fundamental data have been obtained on the severity of lightning duty on such lines or upon the detailed lightning performance of various types of line design and lightning protection. Most of such information has been gathered on the higher-voltage steel-tower lines. A comprehensive lightning investigation of this type has been undertaken jointly by the Public Service Company of Northern Illinois and the Westinghouse Electric Corporation on several types of 33-kv wood-pole circuits.

The study has consisted of four principal parts. A detailed climbing inspection program (correlated with operating results over a $2^1/_2$-year period between 1939 and 1942) was carried out on a 28.8-mile line with the unprotected construction shown in Figure 1. This represents about the optimum amount of line insulation generally feasible for an unprotected line of this voltage class.[1] The inspections have provided valuable fundamental and correlating data on the nature of insulator flashover markings and on the distribution of lightning flashover and cases of sustained power follow between the different types of poles. At the beginning of the 1942 lightning season, two types of recording installations were put in service. One type is for the purpose of determining the character of line flashovers on unprotected lines. Sections of line were chosen where recorders could be placed on poles one-half to one mile apart whose insulation was comparable to a guyed pole, and with fully insulated tangent poles intervening. The line construction for these sections is also that of Figure 1. Photographic surge-current recorders and surge-crest-ammeter links were placed in the grounding circuit. The photographic surge-current recorder, which has been described in detail elsewhere,[2] employs the principle of photographing the luminosity produced by the flow of the surge current across a short spark gap inside of a light-tight case. The film image is produced through a special aperture and set of barriers so constructed that the light from the gap (Figure 5A) spreads in a nonuniform manner over the film perpendicular to its direction of motion. The barriers confine the image to a narrow wedge in the direction of film motion to enable high resolving power with time. The width of the image (in a direction perpendicular to the film motion) and its density provide a measure of the current magnitude. As current is increased, the film is saturated at increasing distances from the center axis. However, at a point just beyond this region, the film density can be measured to determine the approximate current magnitude. Current can be measured to an accuracy of about two to one but over the very great range of 0.1 to 150,000 amperes with a time-resolving power of 600 microseconds. Initially, there were 20 of these installations on three different line sections. However, the recorded prevalence of multiple flashovers extending over a mile or more made it advisable to select a single longer section of line. At present 14 poles on a ten-mile section of the line where the climbing inspection was made are equipped with recorders as shown in Figure 2. Two additional recorders have been placed at each pole to measure both the lightning and power-follow flashover currents from each side phase to a neutral point and from neutral to ground. Thus, it is possible to record for each of these paths the multiple character, duration, and approximate magnitude of the lightning-flashover currents together with the duration and approximate magnitude of the power-follow currents. A longer cross arm has

Paper 45-115, recommended by the AIEE committee on power transmission and distribution for publication in AIEE TRANSACTIONS. Manuscript submitted May 4, 1945; made available for printing May 16, 1945.

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The authors acknowledge the assistance of W. H. Johnson, A. M. Shefveland, and L. J. Davis, of the Public Service Company of Northern Illinois for their assistance in obtaining the fundamental field data of this investigation.

stant-displacement unit. When the push–pull rod which controls the amount of displacement is in the middle position, there is no flow of hydraulic fluid and the pump–motor combination is hydraulically locked together and drives as a unit. The losses at zero differential speed are essentially mechanical—gear and bearings.

By varying the control rod on the pump, the flow is increased. The pump is capable of pumping in either direction, and, therefore, the rotation of the motor will be in one direction or the other, so that its speed will either add to, or subtract from, the speed of the hydraulic pump.

This type of drive has the same advantages of gain in efficiencies as the type previously described and, because of the effective overdrive and underdrive arrangement, is capable of operating over a large speed range.

An advantage of this design is that the speed of the pump and motor combination may be very easily stepped up so that the transmitted torque is low and the unit may be of very light weight.

A unit of this type has been built for less than one pound per horsepower and with an efficiency of 92 to 83 per cent over the speed range.

The sketches in Figures 16 and 17 are of a unit of this design built by the Sundstrand Machine Tool Company. Figure 16 shows the alternator-coupling flange and spline, and Figure 17 is the pad for connecting to the main engine.

Conclusion

The problem of providing a constant drive speed with a variable-speed prime mover is by no means new. There have been many solutions to this problem—electrical, mechanical, and hydraulic. Unfortunately, however, for an aircraft application they have all been too heavy or inefficient. In aircraft design, inefficiency is tantamount to weight for inefficient operation means more fuel is used, which means more weight is carried.

Many forms of constant-speed drives have been suggested and worked upon. It was not within the scope of this report to describe them all, many of which show considerable promise. The ones described in this report have all been at least in experimental production and have given us sufficient background information for us to draw a reasonable picture of the type of constant-speed drive which will soon be making its appearance in large aircraft.

The production units may be expected to have efficiencies of 85 to 95 per cent, a weight of less than one pound per transmitted kilowatt, will hold a preset output speed to within ±1 per cent total variation over an input-speed range of from 500 to 3,000 rpm, and will fit within a space of 50 cubic inches per kilowatt of rating.

The large airplanes of today with a-c systems will have drives of this type. It is probable that with continued development the efficiency will be increased and the size and weight reduced to a point where it may be practical to use a constant-speed drive for d-c generators and other pieces of auxiliary equipment.

been installed lower down on the pole to provide the normal wood insulation path between the insulators and the recorder circuit.

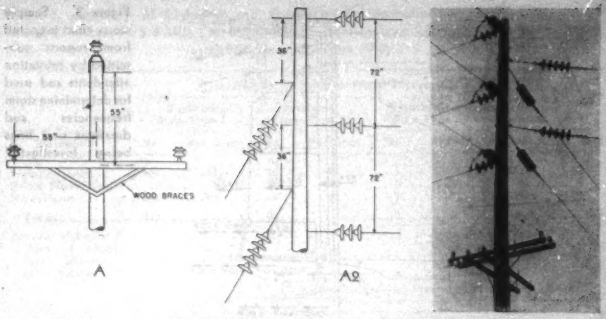
For the second type of recorder installations, surge-crest-ammeter links have been placed in the ground leads of protected lines having the types-4 and 5 overhead-ground-wire construction of Figure 9, lines of type-3 construction (Figure 9) having delon protector tubes on the top conductor only and a line of type-6 construction (Figure 10) having protector tubes on each phase but on only one phase per pole and rotated between phases. The pole-ground-lead current records obtained in this way provide data on the frequency of direct strokes, the crest-stroke currents, and the division of current between ground leads as correlated with line performance. The magnetic links are placed so as to record crest currents ranging from a minimum of about 600 amperes to about 55,000 amperes. The presence of only a single straight conductor for each pole ground enables a more accurate recording of the pole currents than is possible on steel-tower lines where there is a multiplicity of paths down the tower and where only one tower-leg current is usually recorded. In addition magnetic links have been installed on a number of isolated protector-tube installations to correlate the difference in protector-tube duty under the two operating conditions.

In the fourth phase of the investigation a detailed record of the frequency and extent of lightning storms passing over the region occupied by the lines under investigation has been obtained. This was started at the beginning of the 1943 lightning season, and the manner in which it is accomplished is illustrated in Figure 3. Observers at the numbered substations submit a report on the apparent storm centers as illustrated by the samples at the bottom of the chart for every individual storm that they can observe. Each of their observations as to the location and direction of travel (at the time they are first able to observe it, when it passes closest to their observation station, and when they last observe it) and the time of the observation, are plotted, as shown, by an arrow. From these, the storm path, storm extent, and duration over each line can be determined. Such data provide a valuable correlation between the number of annual storm-days, number of storms, total annual storm duration, the frequency of strokes to the various lines, and the number of line tripouts.

Results of Climbing Inspection—Insulator Markings

In the course of the climbing inspection previously mentioned, 8.6 miles of line were inspected after about 1½ years of operation of the line. The remaining 16.8 miles were inspected after about 2.5 years of operation. A total of 180 of the pin-type insulators that had flashover markings were removed from the pole for a more detailed inspection. Typical markings are illustrated by Figure 4. When flashover is first produced by lightning, the path of lowest dielectric strength is along the surface of the porcelain, so that breakdown occurs there first. Thus, for most lightning flashovers, heating of the porcelain glaze is more or less uniform along this flashover surface and results in the "lightning-only" markings illustrated by Figures 4A, B, C. Lightning markings are characterized by roughening of the insulator glaze (with a texture resembling fine sandpaper) over a path closely following the insulator contours. This frequently includes the underside of the top skirt. It may vary in width from a narrow line (Figure 4A) to a wide path extending several inches circumferentially around the insulator (Figure 4B). The length of the lightning markings varies greatly. In some cases there may be only a short narrow mark somewhere on the upper side of the top skirt. For others, the insulator surface may be marked almost continuously from tie wire to the lower edge of the inner skirt. In many cases a multiplicity of lightning paths is found on one insulator (Figures 4A and C). These can be formed by entirely separate lightning strokes or by different components of the same stroke.

In case of power follow, the long-duration arc will tend to move away from the porcelain surface and maintain contact only at its terminals. This results in broad splashes of burned porcelain glaze at these points, often with considerable conductor and tie-wire pitting. The power-follow markings usually are localized in spots on the top and bottom of the insulator where the glaze has been burned through to the porcelain and frequently has a blistered appearance (Figure 4D). In less severe cases the glaze may be only partially burned through and is left with a color lighter than that of the normal surrounding glaze. Then the burned spot may have a crackled rather than blistered appearance. Sometimes the power-follow arc appears to strike from the conductor to the insulator pin, and the principal burn on the top of the insulator is at the edge of the top skirt under the conductor. In other cases, when the arc strikes from the tie wire, burns are found on the upper surface close to the tie wire. A power arc between line conductors usually will leave pits and beads or points of metal, often uniformly spaced out along the conductor from where the flashover started. These are the result of the arc traveling along the line, one melted spot occurring with each half cycle of current. The interpretation



Figures 1 A (left) and B (right). Types of line construction on unprotected line used for detailed climbing inspection and photographic-surge-current-recorder study

A. Type 1, unguyed
When guyed, guy attached 30 inches below crossarm, and insulated with three 5¾-inch suspension units
A2. Type-2 corner pole

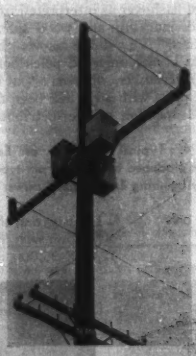


Figure 2. Installation of flashover recording equipment on line construction of Figure 1

Photographic surge-current recorders in both crossarm flashover paths and ground path. Crest-ammeter links in ground path

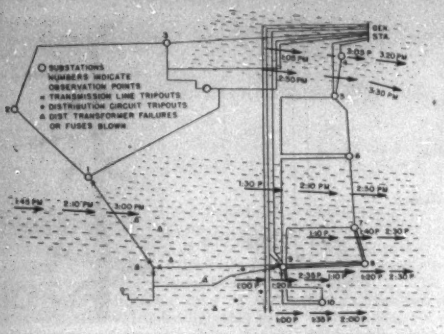


Figure 3. Sample storm chart prepared from reports submitted by substation attendants and used for determining storm frequencies and durations over lines being investigated

Sample Thunderstorm Reports

Observation Station	First Observation			When Over or Nearest Station			Last Observation		
	Time	Direction	Distance	Time	Direction	Distance	Time	Direction	Distance
1	1:45 p.m.	Southwest	7 mi	2:10 p.m.	South	2 mi	3:00 p.m.	East	6 mi
4	1:35 p.m.	Northwest	4 mi	3:05 p.m.	Over		3:20 p.m.	North	2 mi

No storm visible from stations 2 and 3

1—Lightning, thunder, no rain. Seemed to come from southwest, stay two miles south of station, then go east

4—Heavy rain at 3 p.m.

of evidence, as previously described, may not always be infallible, as some lightning strokes probably can have sufficient duration to produce effects resembling those attributed to power follow. Neither are so-called power-follow markings always evidence of sustained power follow causing circuit interruptions, as the 60-cycle arc may be extinguished before a circuit-breaker relay operation. These cases, however, are thought to be infrequent, as is borne out by correlation of similar inspection data with actual flashover-current records that subsequently will be discussed.

Distribution of Line Flashovers

A length of 3.4 miles of the line inspected in detail parallels and is shielded by a 132-kv tower line, with overhead ground wire. The normal heights of the towers and poles above ground are 92.5 feet and 38 feet, respectively. The horizontal distance between tower-line ground wire and ridge-pin conductor on the pole line varies from 88 feet to 99 feet. No evidence of line flashover was found on the inspections. However, one stroke occurred to this section in 1943 as evidenced by a splintered pole. Thus, in $5\frac{1}{2}$ years the section has been struck once.

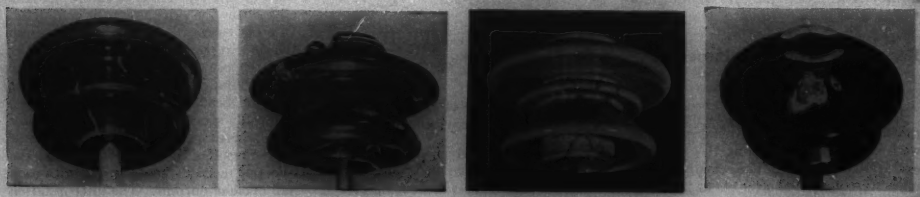
The remaining 25.4 miles of unshielded line on which the climbing inspections were made has 453 poles with an average span of 293 feet. A total of 411 poles are type 1 (Figure 1) unguyed with 108 having a distribution circuit below the high-voltage circuit, 12 poles are guyed type-2 vertical corner poles, and 30 are guyed type-1 poles. Thus about ten per cent of the poles are guyed. Table I presents a summary of the distribution of the two types of flashover as interpreted from the insulator markings and wood splintering inspection. This table shows that 36 per cent of the unguyed poles bore evidence of flashover, whereas about 80 per cent of poles with guys had been flashed over. Inspection of the distribution of flashed poles showed that unguyed poles tend to be protected by guyed poles several spans away. The trend in the case of power-follow arcs is more significant. Only 13 per cent of the tangent unguyed poles that flashed over had evidence of power follow, whereas the percentage for the guyed type-1 poles was 42 and for the vertical corner poles (with still lower insulation to ground) 90. As far as can be determined, the presence of distribution circuits or transformers (distribution arm five feet below transmission arm) has little bearing on the effects of lightning on the transmission line, 34 per cent of poles with distribution having flashover evidence. This particular analysis cannot determine accurately the actual number of individual cases of each type of flashover. However, it provides very significant evidence on the nature of the flashover of such lines which can be discussed more clearly when correlated with the additional data obtained from the photographic-recorder measurements.

Character of Flashovers on Unprotected Line

The section of line equipped with the photographic recorders is inspected after each storm, the photographic recorders and magnetic links being checked for flashover-current records together with a visual inspection for additional flashover evidence. Where necessary, a climbing inspection is made as frequently as possible to determine the location and type of insulator markings and other evidence not visible from the ground. This is for the purpose of detecting flashover on intervening poles not equipped with recorders and to provide correlating information with the flashover currents at the recorder poles. During the three-year period 49 cases of line flashover have occurred on the sections under investigation for which it could be determined whether or not a sustained power follow or a line tripout was produced. For 35 cases a detailed record was obtained of the number of poles flashed over, together with the type of lightning flashover and sustained power follow (if occurring) at each pole. It is recognized that the mechanism of arc restriking and dielectric recovery is quite

Figure 4. Typical example of flashover markings produced on 34.5-kv pin-type insulators by lightning flashover and power follow

A. Lightning only, seven paths B. Lightning only C. Lightning only after four recorded cases of flashover with crest currents of 12,500, 12,000, 35,000, and 22,000 amperes D. Two power-follow markings and lightning track



complex, being a function of a large number of factors that cannot be evaluated adequately from the data so far obtained. However, there are certain important facts that have been ascertained which are described here briefly.

One of these is the prevalent occurrence of simultaneous flashover produced over an extended section of line by a single stroke. It was found that a stroke occurring between recorder stations usually flashes over several of the unguyed poles in the vicinity of the stroke in addition to one or more of the recorder poles having the lower insulation to ground. This is illustrated by the records of Figures 5A and B. Figure 5A is typical of several obtained showing simultaneous flashover for each component of a multiple stroke. It is the usual case that, if an appreciable duration of the lightning current is indicated for any one stroke component, it frequently occurs only at one pole, the same pole having power follow when present. Figure 5B is another record showing simultaneous flashover produced over about 1.5 miles of line. For this case, although lightning flashover occurred between all three phases and ground at pole 280 power follow occurred only between the top and one side conductor. Evidence of similar multiple-flashover characteristics on 220-kv wood-pole lines has been presented elsewhere.[3]

Character of Voltages Produced by Direct Strokes to Unprotected Lines

The data presented by the foregoing two types of study provide definite substantiation of the nature of the voltage produced by direct strokes as visualized from our present knowledge of stroke mechanism.[4] This is illustrated by Figure 6. Strokes to open ground or to relatively low structures such as transmission lines are initiated by streamers propagating from cloud to ground (Figure 6A) which lower charge at a relatively slow rate onto the stroke channel being formed. During this period the electric field at the ground is being increased at an accelerating rate. During the initial stages of this process charge of opposite polarity to that on the stroke channel can flow along the conductor into the region below the stroke channel neutralizing this effect and holding the conductors at ground potential. However, at some instant before stroke contact, the rate of change of field produced by the stroke exceeds the rate at which charge can be drawn in on the conductors, and the conductor potentials start to rise (Figure 6B). It is indicated[4] that such induced voltages may start to be appreciable from 50 to 250 microseconds before actual stroke contact and reach magnitudes ranging from 100 to at least 1,000 kv. Just before the start of the "return-streamer" process (Figure 6A), short upward streamers may occur from the conductor, tending to modify the voltage to varying degrees. However, the general character of the voltage is one of an accelerated rate of rise which would become greatest after stroke contact (at the instant of maximum rate of current rise on the front of the discharge-current wave) if flashover did not occur first.

For such lines as being considered here, the voltage easily can reach the insulation strength to ground of a guyed pole in the initial period before actual stroke contact. Being of a slow rate of rise, it will cause flashover at the lowest insulation point, even though it be several miles distant. After stroke contact, the much higher rate of rise also may produce flashover at or near the point of contact. Further, the initial breakdown of wood insulation usually is just inside the surface, resulting in very high arc drops that frequently permit the simultaneous flashover of a number or adjacent unguyed poles (sometimes ten of more). Thus strokes to such lines should set up several simultaneous discharges as shown by the climbing inspection and photographic-recorder data. Parallel arc paths are very unstable, and one will tend to rob the others of the arc. This should be the path with lowest rate of dielectric recovery as characterized by the length and type of flashover medium and the magnitude and duration of current it has conducted. It would be expected that any sustained arcs would tend to concentrate at the guyed poles with flashover paths producing the lowest arc impedance and rate of dielectric recovery. As shown by Table I, 50 per cent of the poles showing power-follow evidence were guyed poles that constituted only ten per cent of the total poles. If the number of individual cases of power follow could have been counted accurately, the percentage probably would have been still higher. As previously mentioned, the unstable character of simultaneous arcs usually results in the concentration not only of the power follow but also the long-duration portion of each stroke component at

Table I. Summary of Lightning and Power-Follow Inspection on 33-Kv Unprotected Wood-Pole Line—25.4-Mile Line—453 Poles—Average Span 285 Feet—Line Put in Service 1939, Last Inspection 1941

Type of Flashover Evidence	Number of Poles on Which Evidence Was Found							
	Unguyed Pole Type 1		Insulated Guys Type 1		Vertical Corner Pole Type 2		Total Poles	
	No.	Per Cent	No.	Per Cent	No.	Per Cent	No.	Per Cent
Lightning only	127	31	14	47	1	8	142	31
Power follow also	19	5	10	33	9	75	38	8
No evidence	265	64	6	20	2	17	273	61
Totals	411		30		12		453	
Per cent of flashed poles of each type showing power follow		13		42		90		

	Positive Critical Dry Flashover Values in Kilovolts		
	Unguyed Type 1	Guyed Type 1	Vertical Corner Type 2
Top conductor to lower conductor	1,100	1,100	935
Top conductor to ground	(3,000–4,000)	1,000	950

Table II. Lightning Exposure and Performance of Unprotected 33-Kv Wood-Pole Lines

Line No.	Predominate Construction	Length, Miles	Number of Storm-Days			No. of Separate Storms			Total Storm-Hours		Tripouts Per 100 Miles Per Year		
			1942	1943	1944	1942	1943	1944	1943	1944	1942	1943	1944
A	Types 1, 2	23.8	27	20	25	29	27	31	31.5	40.5	80	38	13
B	Types 1, 2	10.2	16	19	18	17	24	21	25	25	49	29	30
C	Types 1, 2, 7*	58.9	22	27	36	32	32	42	42.5	78	78	61	73
D	Type 7*	27.1	17	31	28	20	35	35	43	43	44	44	15
E	Types 1, 2	10.6	18	21	42	21	28	47	33	21	38	66	21

* Type-7 lines with flat configuration, ten-foot crossarms, steel braces, and no guy insulation.[1] Critical breakdown voltages at tangent poles = 590 kv line-to-line, 3,000–4,000 line-to-ground. At guyed crossarm poles 325 kv line-to-ground, at vertical corner poles 600 kv line-to-line and 350 kv line-to-ground. For 4,090 mile-years (1929–32) average tripouts per 100 miles per year = 38.
Lines of types 1 and 2 construction (see Figure 1 and Table I). For 571 mile-years (1938–44) average tripouts per 100 miles per year = 31.

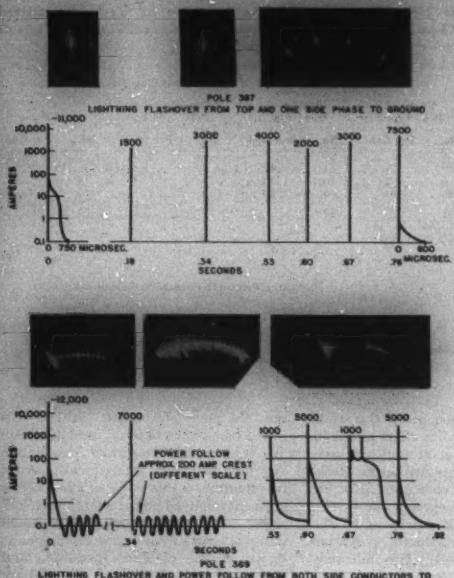

POLE 387
LIGHTNING FLASHOVER FROM TOP AND ONE SIDE PHASE TO GROUND
AMPERES
SECONDS
POLE 369
POWER FOLLOW APPROX 200 AMP CREST (DIFFERENT SCALE)
LIGHTNING FLASHOVER AND POWER FOLLOW FROM BOTH SIDE CONDUCTORS TO GROUND (TRANSPOSITION BETWEEN POLES 369 AND 387)

Figure 5A. Photographic surge-current record of multiple-lightning flashovers produced simultaneously at two recorder stations with power follow at one

Three tangent poles adjacent to pole 387 had lightning-flashover evidence. Photographic recorders were installed only in ground path. Distance between recorders is one mile. First component started power follow at pole 369 that apparently extinguished itself; second component started power follow extinguished by breakers. Additional components occurred after circuit was interrupted

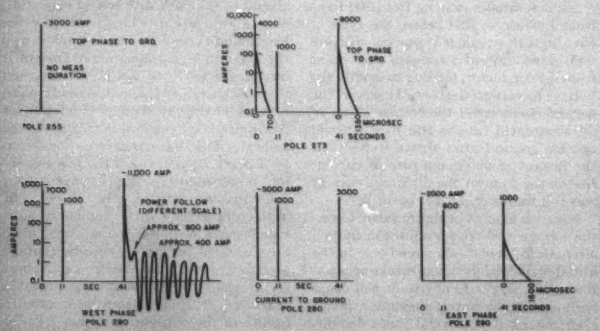


Figure 5B. Photographic surge-current record of lightning flashover produced at three recorder poles approximately one mile and one-half mile apart, by a three-component multiple stroke causing a phase-to-phase fault at pole 280

Recorders in ground path only at poles 255 and 273. Pole 280 showed minor pole and crossarm splintering indicating flashover from all three phases. All three insulators showed lightning flashover with power-follow marks on ridge and west phases

one location with only very short duration at the other flashed paths.

Character of Recorded Flashovers

For the total of 49 recorded cases of flashover 21 or 43 per cent caused a sustained power follow. For 35 of these the type of flashover at each pole could be identified. Of these the lightning flashovers at the recorder poles consisted of 18 single line to ground, eight double line to ground, and nine involving all three phases and ground. However, all but five involved lightning flashover between more than one phase at some point along the line. Fifteen or 40 per cent of the 35 caused a sustained power follow. All but three of these occurred at the guyed poles. Eight of the power follow cases were single line to ground, six double line to ground, and one line to line. Thus, although 30 out of 35 cases caused multiphase lightning flashovers, only seven or 20 per cent caused a sustained multiphase fault. In addition to the 15 out of 35 recorded cases of sustained power follow, one case of $3^1/_2$ cycles of power follow and one of one cycle of power follow were recorded (apparently self-extinguishing) together with a case in which sustained power follow was initiated after the third component discharge at one recording station while the same three-stroke components produced one, two, and one-half cycle, respectively, of power follow at an adjacent station.

It is of interest that the insulator inspection records of flashover at each recorder pole correlated quite well with the flashover-current records. In every case where only lightning-flashover currents were recorded, the insulator markings were interpreted as "lightning only." The same correlation was obtained for the cases of power follow except that no marked distinction could be made between the cases of sustained power follow, requiring operation of the eight-cycle breakers, and the power follow cases that lasted from 1 to $3^1/_2$ cycles. Also in one case power-follow evidence was not discernible at one of the two insulators shown by the recorders to have been involved in a sustained arc.

Storm Frequencies and Durations

Tables II and III list the data obtained on the number of storms, storm days, and total storm hours per year recorded over each of the unprotected and protected lines being investigated. These data were obtained from the storm charts prepared as illustrated in Figure 3. Correlated with the data are the number of tripouts per 100 miles of line per year and the number of strokes to the protected lines continuously equipped with magnetic links. It is of interest that although the ratio between storm-days, storms, and storm-hours varies considerably as does also the magnitude of each of these quantities from year to year and between different lines, the order of magnitude of all three is the same. No one of the above three indexes of storm activity appears to bear a closer relation to the frequency of direct strokes or line tripouts than the others. This indicates that the intensity of the electric storm or the density of direct strokes to ground is a variable of at least as great importance as the others.

Crest Stroke Currents

Before discussing in more detail the relation between the frequency of storms, direct strokes, and line tripouts, it would be best to examine the magnetic-link rec-

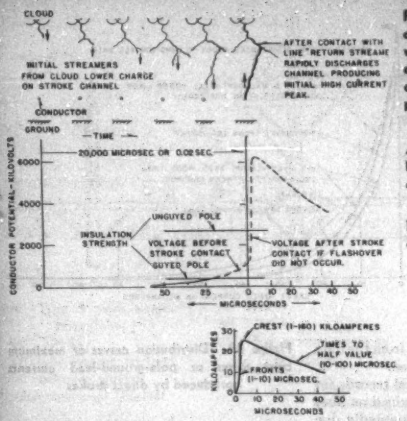


Figure 6. Mechanism of the direct-stroke discharge by which relatively high voltage of slow rate of rise can be induced upon conductors of unprotected transmission lines before actual stroke contact

A (left). Voltage produced by direct stroke to conductor of unprotected 33-kv wood-pole line

B (below). Assumed stroke current and principal ranges of variation[3]

ords of pole-ground-lead currents upon which the stroke-frequency data are based. It is first necessary to consider the possible sources of surge currents that might produce a record. These are somewhat different for lines having an overhead ground wire than for lines equipped with protector tubes. As has been pointed out previously,[3] not only direct strokes but indirect strokes striking nearby can induce smaller magnitude currents in the ground leads. At least 90 per cent of all strokes to ground are negative which will induce positive currents in the ground leads. It was estimated[4] that for spans of 800–1,000 feet, induced currents as high as 5,000 amperes might be produced in a single tower of an overhead-ground-wire line. Similar estimates indicate possible induced currents as high as 1,500 amperes for spacings between ground leads of the order of 300 to 400 feet. For lines equipped with protector tubes higher currents can be produced, because such an indirect stroke will flash over a relatively few tubes and thus provide a limited number of paths to ground. Another important source for ground-lead-current records on lines equipped with tubes is the simultaneous flashover of a tube of lower breakdown voltage some distance away from the point of stroke contact due to the previously mentioned initial slow rate of voltage rise. Thus, an appreciable number of isolated pole-ground-lead-current records can be produced simultaneously with those close to the point of stroke contact. For the afore-mentioned reasons it is important to consider the crest-ammeter records carefully.

Such factors have been recognized to some extent in previous magnetic-link investigations on higher-voltage lines[6,7,8] and some sort of arbitrary method set up for throwing out certain records and not identifying them with direct strokes. However, in plotting the results of such previous studies it has been customary to plot percentage distribution curves showing the per cent of records exceeding a given magnitude. When this is done the character of the resulting curve depends to a great extent upon the accuracy of the judgment used and the number of records eliminated. A more fundamental way to approach this problem is to plot the total number of records (or the number per 100 miles of line per year) that exceeds each magnitude. The resulting curve will eliminate the afore-mentioned judgment factor except for the lower range in which other sources can produce records. This is important, as it is the higher-magnitude currents that are most likely to cause a flashover. Curves plotted in this way from this investigation are shown in Figure 7A together with a similar analysis of the Hansson and Waldorf data[8] in which all records thought by them to be direct strokes were used. Figure 7B presents a comparison of the more generally used percentage distribution curves from this and other investigations. The curve of Figure 7A for 33-kv lines with an overhead ground wire shows more high-current records than either the 33-kv protector-tube-line data or the steel-tower-line data. This same trend is shown for the individual maximum crest pole-ground-lead currents associated with each stroke. It was not found that any significantly greater number of grounds on the overhead-ground-wire lines tended to carry current than for the protector-tube lines. This indicates that more of the higher-current strokes actually were recorded on the ground-wire lines. This curve is based upon only 66 records, and for this reason a definite conclusion cannot be reached. However, it is of interest that an analysis of the data obtained by Hansson and Waldorf[8] from different lines indicates curves agreeing quite closely as long as about 100 records were available for each curve.

The factors which might affect such curves may be summarized briefly as follows: Because of the traveling-wave effect the sum of the crest tower currents should be greater than the actual crest stroke current. The difference will be greater the shorter the wave front and the longer the span. Further the sum of the crest tower currents is the sum of the respective maximum components as produced by several component discharges (in the case of multiple strokes) which

Figure 7A. Probability curves showing the number of recorded stroke currents per 100 miles of line per year exceeding a given crest magnitude

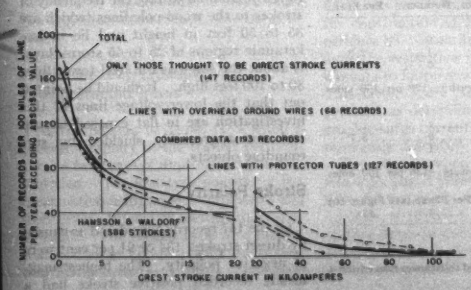
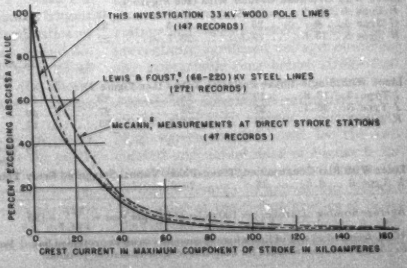

TOTAL
ONLY THOSE THOUGHT TO BE DIRECT STROKE CURRENTS (147 RECORDS)
LINES WITH OVERHEAD GROUND WIRES (66 RECORDS)
COMBINED DATA (193 RECORDS)
LINES WITH PROTECTOR TUBES (127 RECORDS)
HANSSON & WALDORF[7] (588 STROKES)
NUMBER OF RECORDS PER 100 MILES OF LINE PER YEAR EXCEEDING ABSCISSA VALUE
CREST STROKE CURRENT IN KILOAMPERES

Figure 7B. Percentage distribution curves of direct-stroke crest currents


THIS INVESTIGATION 33 KV WOOD POLE LINES (147 RECORDS)
LEWIS & FOUST,[5] (66-220) KV STEEL LINES (2721 RECORDS)
McCANN,[5] MEASUREMENTS AT DIRECT STROKE STATIONS (47 RECORDS)
PERCENT EXCEEDING ABSCISSA VALUE
CREST CURRENT IN MAXIMUM COMPONENT OF STROKE IN KILOAMPERES

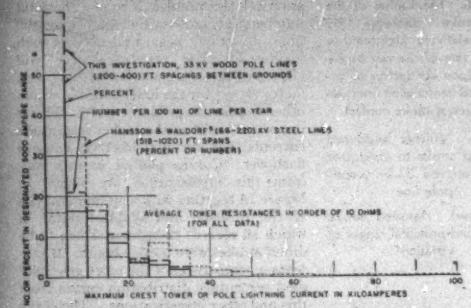

THIS INVESTIGATION, 33 KV WOOD POLE LINES
(200-400) FT. SPACINGS BETWEEN GROUNDS
PERCENT
NUMBER PER 100 MI OF LINE PER YEAR
HANSSON & WALDORF[4] (66-220) KV STEEL LINES
(518-1020) FT. SPANS
(PERCENT OR NUMBER)
AVERAGE TOWER RESISTANCES IN ORDER OF 10 OHMS
(FOR ALL DATA)
NO. OF PERCENT IN DESIGNATED 5000 AMPERE RANGE
MAXIMUM CREST TOWER OR POLE LIGHTNING CURRENT IN KILOAMPERES

Figure 8A. Distribution curves of maximum crest tower or pole-ground-lead currents produced by direct strokes

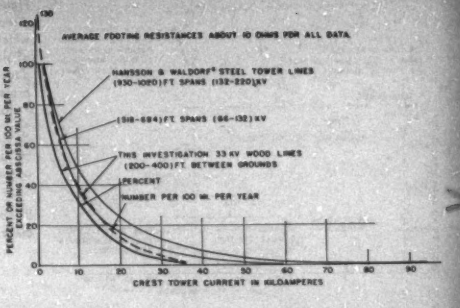

AVERAGE FOOTING RESISTANCES ABOUT 10 OHMS FOR ALL DATA
HANSSON & WALDORF[4] STEEL TOWER LINES
(930-1020) FT SPANS (132-220) KV
(518-684) FT SPANS (66-132) KV
THIS INVESTIGATION 33 KV WOOD LINES
(200-400) FT. BETWEEN GROUNDS
PERCENT
NUMBER PER 100 MI. PER YEAR
PERCENT OR NUMBER PER 100 MI PER YEAR EXCEEDING ABSCISSA VALUE
CREST TOWER CURRENT IN KILOAMPERES

Figure 8B. Distribution curves of maximum crest tower or pole-ground-lead currents produced by direct strokes

might not bear the same proportionate relation to each other and cause the data to be high. Further, the effect of several strokes in some cases may be considered as one. On the other hand, magnetic-link measurements on steel-tower lines will indicate less than the total tower current, as no account usually is taken of the cross-brace currents.[5] There is one more very important effect that might account for the higher stroke currents on the 33-kv line with ground wires as compared to the 33-kv protector-tube-line data. The availability of the charge from ground that must combine with the stroke charge can be appreciably greater for a line with overhead ground wires. Then, there is a large number of paths provided by each ground lead, whereas for the tube line the only paths are those provided by the tubes that flash over. The possibility of more rapid combinations of the charges for the former case might result in a prevalence of higher crest currents. Although this effect cannot yet be definitely verified from the data so far obtained, it is indicated.

The higher number of total records (or low-magnitude records) obtained on lines with protector tubes is undoubtedly due to the two factors mentioned previously, induced surges, and simultaneous flashover. For instance, of 127 records to the tube lines, 57 were isolated surges involving only a single pole ground. Fifty per cent of these were positive. Of the 66 records from the ground-wire lines only eight (75 per cent positive) were of this nature. This latter would be expected, as they should be caused predominantly by indirect strokes. In order to form a basis for eliminating all but those records thought to be caused by direct strokes, all isolated tower-current records (involving only one pole) below 1,500 amperes for overhead-ground-wire lines and below 5,000 amperes for protector-tube lines were arbitrarily removed from the data. This produced the lower solid curve in Figure 7A.

Frequency of Direct Strokes

The curve obtained in this way gives an average of 130 direct strokes per 100 miles of line per year. Hansson and Waldorf[4] estimate a general average of 100 strokes per year from their studies on steel lines. However, as shown by the curve of Figure 7A their data represent the number exceeding about 2,500 amperes (the lower limit of their recorders). This point lies very close to the corresponding point on the combined curve of this investigation, which indicates that they also would have measured more actual direct strokes if conditions had permitted the recording of lower-magnitude direct strokes. On the other hand, when comparing the percentage distribution curve obtained by the foregoing method of removing certain records with the curve obtained in the Westinghouse direct-stroke investigation (Figure 7B) it is seen that a higher percentage of lower-magnitude records is still present in the data of this investigation. The direct-stroke study shows that about ten per cent of all direct strokes are below 2,000 amperes and 16 per cent are below 5,000 amperes, whereas the curve of this study shows corresponding percentages of 15 and 30. Adjustment of the data of this study to fit the direct-stroke data in this range would produce a curve in Figure 7A that would indicate about 95 direct strokes per 100 miles of line per year. It appears evident that, with a possible range of from 95 to 130, the frequency of strokes to the wood-pole lines (which are 35 to 50 feet in height and lie in isokeraunic regions of 25 to 45 storm-days) is about the same as for steel-tower lines 80 to 100 feet high. It should be pointed out that the lower-voltage lines of this investigation are in flat exposed terrain and not appreciably shielded by surrounding objects.

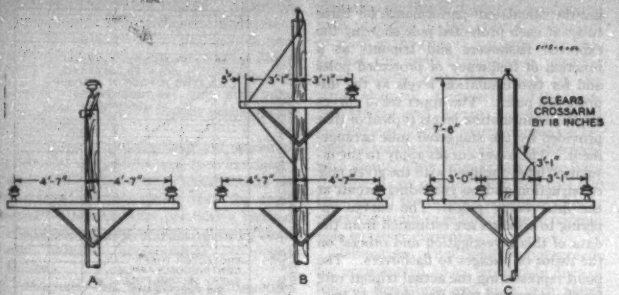
Table III. Lightning Exposure of Protected 33-Kv Wood-Pole Lines

Line	Mile-Years	Storm-Days Per Year	Storms Per Year	Storm-Hours Per Year	Total Direct Strokes	Total Tripouts	Normal Tripouts From Lightning: Number	Normal Tripouts From Lightning: Number Per 100 Miles Per Year
Lines With Overhead Ground Wire (see Figure 9)								
F Type 4	21.9	25.3	30	43	21	0	0	
G Type 4	9	23	28.5	33	19	1	1	2.3
H Type 5	13.5	19.7	28.7	22	13	0	0	
					53	Average density—120 per 100 miles per year		
Lines With Single-Phase Protector Tubes (see Figure 9)								
I Type 3	13.8	19.7	28.7	22	24	2*	1	
J Type 3	36.3	27	39	27	49	0	0	3.7
K Type 3	3.4	23	25.3	33	11	1	1	
					84	Average density—136 per 100 miles per year		
Lines With Flat Construction, Three-Phase Tubes, Staggered Every Third Pole Per Phase (see Figure 10)								
L Type 6	8.5	23	25.3	33	10	2	2	43

Average number of strokes per 100 miles of line per year $= \frac{147}{112.7} = 130$.

*One occurred at end of line where it connects to an unprotected line. Pole ground resistances range from 3 to 20 ohms with an average for each line of approximately 10 ohms.

Of the 147 records considered as caused by direct strokes, 134 or 91 per cent were of negative polarity. The highest-magnitude recorded positive stroke had a

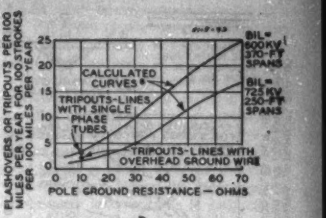


A. Type 3 with single-phase tubes
BIL 725 kv
370-foot average spacings between grounds
Average spans 185 feet

B. Type 4
BIL 725 kv
250-foot average spacings and spans

C. Type 5
BIL 600 kv
320-foot spacings and spans

Figure 9. Comparison of actual and calculated performance of three types of 33-kv protected line construction employing an overhead ground wire or deion protector tubes on a top phase


FLASHOVERS OR TRIPOUTS PER 100 MILES PER YEAR FOR 100 STROKES PER 100 MILES PER YEAR
25
20
15
10
5
0
CALCULATED CURVES
TRIPOUTS—LINES WITH SINGLE-PHASE TUBES
TRIPOUTS—LINES WITH OVERHEAD GROUND WIRE
BIL = 600 KV 320-FT SPANS
BIL = 725 KV 250-FT SPANS
0 10 20 30 40 50 60 70
POLE GROUND RESISTANCE — OHMS

D.

crest current of 90,000 amperes and the highest negative stroke 113,000 amperes.

Pole-Ground-Lead Currents

Figure 8 presents the data on the maximum pole-ground-lead currents for each record identified as a direct stroke and compared with similar data of Hansson and Waldorf.[6,7] In these figures the data are plotted in two ways showing both the per cent and the number of tower currents per 100 miles of line per year corresponding to the given values. Since the average recorded direct strokes for the Hansson and Waldorf data is 100 per 100 miles per year, their curves for the two ordinate systems coincide. These curves show the benefit of short spacings between spans in reducing the maximum tower current. The highest-pole ground lead current recorded for the 33-kv lines of this investigation is 36,000 amperes as compared to a maximum of 95,000 amperes for the steel-tower lines with longer spans.[6] As shown by Figure 8B the maximum pole-ground-lead current produced by five per cent of the strokes to the wood-pole lines with the shorter spans is 26,000 amperes whereas the corresponding value for the 500–700-foot-span steel lines is 38,000 amperes and for the 900–1,000-foot-span lines 49,000 amperes.

Flashover Performance of Unprotected Lines

At the bottom of Table II is listed a general summary of the tripout performance of two types of unprotected line construction. The first type consists of flat construction using ten-foot crossarms and steel braces typical of installations prior to 1929.[1] The second type of construction is that of Figure 1 with the insulation levels listed in Table I. For both types of construction the average frequency of guyed poles is about once every half to one mile with spans of 150 to 300 feet. As shown in Table II, the flat construction experienced an average of 38 tripouts per 100 miles per year as compared to only 31 for the construction of types 1 and 2 (Figure 1). It is indicated that this improvement in performance is due partly to a reduction of lightning flashovers because of the higher insulation level but that a greater effect is the improvement of the dielectric-recovery characteristics of the line with greater wood insulation.

It has been recognized for some time that a path over wood has a greater "arc-quenching" action than through air or over insulators alone. Studies of the performance of higher-voltage steel-tower lines[8,9] show that about 85 per cent of the flashovers of lines 100 miles in length or less result in a tripout. Calculations from present direct-stroke data[2,9] (including the crest-stroke-current curve (Figure 7A) of this investigation) indicate that lines of the earlier flat construction should experience about 91 lightning flashovers per 100 miles per year, whereas the construction of Figure 1 should experience 88. From the foregoing tripout data the respective percentage ratios of tripouts to flashovers are thus 42 and 35. This latter figure compares with 40–43 per cent as determined from the photographic-surge-current-recorded studies previously described.

The concentration of cases of power follow at guyed poles suggests the possibility of materially reducing the outages on lines of Figure-1 construction by installing deion protector tubes either at or adjacent to all guyed poles. An investigation program of this type is planned.

For best protection tubes should be installed on all three phases since, as shown by the special flashover study, most strokes to such lines result in multiphase lightning flashovers, even though the ridge-pin conductor shields the other two.

Performance of Continuously Protected Lines

Table III summarizes the lightning performance of the protected lines being studied in detail. Only one tripout and case of flashover evidence has occurred for an estimated 53 direct strokes to the lines with an overhead ground wire. The type-3 (Figure 9) construction with single-phase protector tubes has experienced three tripouts for 84 direct strokes. However, Line 1 (Table II) is connected to an unprotected line section, and one of the flashovers occurred at the end pole of the protected section which is also a transposition point. This, therefore, was not attributed to the protected construction. Both of the other two tripouts were associated with tube failures. Thus, the ground-wire lines averaged one tripout per 53 strokes as compared to one per 42 strokes for the single-phase tube construction.

Figure 9 gives the actual number of tripouts per 100 miles of line per year for the combined lines of the two aforementioned general types as compared to calculated performance[2,9] using the stroke-current wave-shape data of direct-stroke studies[8] and the crest-stroke-current frequency curve of Figure 7A. The character of the lightning voltages on an overhead ground wire or a conductor equipped with protector tubes is quite different from that appearing on an unprotected phase conductor.[9] The multiple grounds provided continually for the grounded wire and after a relatively low voltage has been reached by the tubes prevent any significant voltages occurring any appreciable time before stroke contact. Thus the voltages on such conductors are determined primarily by the stroke discharge current. Surprisingly close agreement is shown by the calculated and actual data of Figure 9, indicating that when the actual frequency of direct strokes is known our present knowledge of the characteristics of lightning-stroke currents[2,8,9] provides a reliable basis for determining line perform-

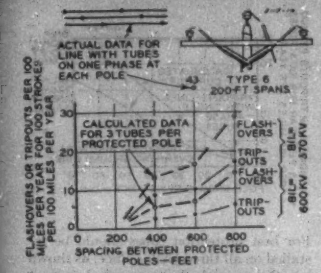


Figure 10. Calculated lightning performance of 33-kv line equipped with protector tubes on all three phases showing effect of spacing between protected poles and insulation at unprotected poles

Also comparison is made with operating performance of line with one tube per pole rotated between phases

ance. As shown in Figure 9, the somewhat higher outage rate for the tube construction is due to its lower insulation level and longer spans as compared to the ground-wire lines. By separating the pole ground lead from the pole,[8] it is quite practical to reduce the flashover rate for this type of construction by about one half. It should be pointed out that the calculated curves apply to flashovers whereas the operating records are tripouts. However, a detailed line-inspection program has been carried out on these lines which so far has detected no flashovers other than those resulting in the tripouts. These inspections are made periodically at all locations shown by the magnetic-link records to have received a direct stroke. That the application of protector tubes only on the ridge conductor of lines such as that of type 1 (Figure 1) provides both an effective and economical method of protection had been shown by previous experience.[10]

The second type of protector-tube application studied in detail is that shown in Figure 10 with a single tube at each pole but the tubes rotated between phases. As shown by the operating data for this construction (Table III) the performance has not been so good as for the other protected lines. For only ten direct strokes there have been two tripouts. One of these flashovers occurred at a switch pole near one end of the line section. The poorer performance is due primarily to the lower insulation level that results from the tube grounds at each pole. This is illustrated by Figure 10. The performance of such construction should be comparable to that with all three tubes installed at every third pole and the same phase-to-phase insulation level at the unprotected poles as provided by the staggered construction at each pole. In Figure 10 are curves showing the calculated[9] performance for three tubes at each protected pole showing the expected flashovers and tripouts as a function of frequency of protected poles and for two insulation levels at the unprotected poles. The upper set of curves applies to insulation levels typical of that provided by the staggered tube arrangement. The lower curves apply to the insulation level obtained with the given pole construction and no grounding circuit at the intervening poles. The curves applying to tripouts are estimated from the data of this investigation and others[9] on the ratios of outages to flashovers. The point representing the actual tripout rate for the staggered tube line shows 43 tripouts per 100 miles of line per year as compared to an estimated 17 flashovers and 12 tripouts, whereas, if the tubes actually had been placed three to a pole every third pole, the estimated flashover rate would have been only seven with four tripouts per 100 miles of line per year.

Duty on Deion Protector Tubes

The records of the lightning surge currents discharged by deion protector tubes are summarized in Figure 11. Two general types of application were studied. One consists of tubes applied continuously on the lines of Table III for which the bottom curve of Figure 11 applies. For the other type of application isolated groups of two to four poles adjacent to a vertical corner pole are equipped with one tube on the ridge-pin conductor. For both curves of Figure 11 all recorded surges are considered, although several tubes might be involved in one disturbance. The much greater tube duty for isolated applications is shown. Each protector tube at the infrequent installations discharged about once per year as compared to a frequency of 0.35 discharge per tube on the continuously protected lines. The tube duty should be considered from two viewpoints, one the duty imposed by high lightning currents and the other by the interruption of fault current. As shown by Figure 11 the tubes at isolated locations discharged about 12 times as many of the higher lightning currents. The actual duty from interrupting fault current depends upon the number of tubes involved for each disturbance. This is not known. In most cases it should be only one. Upon the assumption that one tube interrupts a fault current for every case of flashover, the average number of cases of fault-current interruptions is 0.7 per tube per year for the isolated installations and only 0.17 for the continuously applied tubes; a ratio of about four to one. These differences should be even more marked if cases of single isolated tube-equipped poles were considered. The foregoing data show the material benefit of closely spaced tubes in reducing the individual

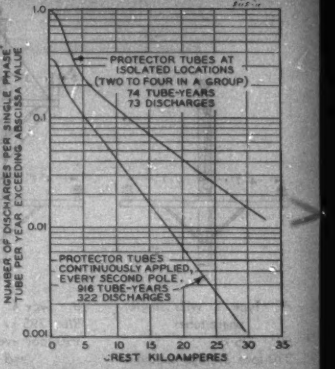

1.0
0.1
0.01
0.001
NUMBER OF DISCHARGES PER SINGLE PHASE TUBE PER YEAR EXCEEDING ABSCISSA VALUE
PROTECTOR TUBES AT ISOLATED LOCATIONS (TWO TO FOUR IN A GROUP)
74 TUBE-YEARS
73 DISCHARGES
PROTECTOR TUBES CONTINUOUSLY APPLIED, EVERY SECOND POLE
916 TUBE-YEARS
322 DISCHARGES
0 5 10 15 20 25 30 35
CREST KILOAMPERES

Figure 11. Surge-crest-ammeter records of the discharge duty on deion protector tubes installed on 33-kv wood-pole transmission lines

tube duty and maintenance. After 916 tube-years of experience with lines continuously protected by about 320 tubes, there have been three tube failures.

Conclusions

An analysis of the electric fields produced by the "initial streamers" of direct strokes to an unprotected transmission line indicates that surge voltages of appreciable magnitude can be induced on a conductor as much as 50 to 250 microseconds before actual stroke contact. These may reach potentials ranging from 100 to over 1,000 kv before the stroke actually discharges into the line. This is confirmed by a detailed climbing inspection of an unprotected 33-kv wood-pole line and by 49 recorded cases of flashover on sections of unprotected line equipped with photographic surge-current recorders. Having relatively slow rates of voltage rise, these "initial streamers" can flash over points of lower insulation several miles from the stroke, after which higher insulation close to the stroke also may be flashed over by the much higher rates of rise following actual stroke contact.

In the special flashover studies simultaneous multiple flashovers were recorded that extended over as much as two miles of line. In some cases they were caused by multiple strokes, and each component of the multiple discharge was recorded at several of the flashover points. In these cases one path usually (but not always) robs the others of the long-duration portion of each stroke component so that the flashovers at the other points along the line are of very short duration with no evidence of power follow except at the one location.

About 40 per cent of the recorded cases

of flashover caused a tripout. Although about 85 per cent produced a multiphase flashover at some point, only 20 per cent resulted in a sustained multiphase fault. The concentration of power follow at guyed poles shows that they determine to a great extent the tripout performance of such lines.

Examination of the flashover markings produced on 34.5-kv pin-type insulators and correlated with measurements of flashover currents shows that the character of the markings provides a method of detecting flashover from lightning alone and flashover accompanied by power follow.

Magnetic-link studies on continuously protected 33-kv wood-pole lines 35 to 50 feet high show that the direct-stroke frequency is of the order of 95 to 130 per hundred miles of line per year or the same order of frequency as higher-voltage steel-tower lines 80 to 100 feet high lying in regions of about the same lightning severity. Storm observations at substations provide a method of plotting storm maps for each lightning storm over the area covered by the lines being studied. Detailed records of storm frequencies and durations show a wide fluctuation in the number of storm-days, storms, and total annual storm durations both from year to year and between different lines only a few miles apart. As shown by the storm maps, this is caused by large local variations in the extent and paths of the storms. No one of the three indexes bears a close relation to the frequency of direct strokes to the line. This is probably due to the importance of an additional factor, the density of strokes emanating from each storm.

It was found that a more accurate and fundamental method of plotting crest stroke currents and tower currents is in terms of the number per unit length of line per year rather than the per cent that exceed a given value. Because of the uncertainty of the lower-magnitude surges the latter method can produce considerable error in the frequency of the more important higher-current records. There is an indicated prevalence of higher-magnitude strokes to lines equipped with overhead ground wire. A possible explanation for this is the better conducting path provided by the greater number of grounds in the case of a ground-wire line, so that the earth charges may combine more rapidly with the charge on the stroke channel. Comparison of the crest-pole ground lead currents recorded in this investigation (where average spacings between grounds range from 250 to 400 feet) with similar data from high-voltage lines (having spans ranging from 500 to 1,000 feet) shows the definite benefit of closely spaced grounds in reducing the maximum pole or tower currents.

Comparison of lightning-tripout records for unprotected 33-kv wood-pole lines of limited insulation and lines with about the optimum insulation for this voltage class (see Table II and Figure 1) shows an average rate of 38 tripouts per 100 miles of line per year for the former as compared to 31 for the latter.

Detailed data have been obtained on the lightning performance of 33-kv wood-pole lines continuously protected both by overhead ground wires and by protector tubes. Although only a relatively few mile-years of experience have been gained on each type of construction, the detailed nature of the records showing actual stroke frequencies together with line tripouts have established the degree of performance of the various types of construction. Lines equipped with an overhead ground wire and having insulation levels of 600 to 725 kv with spacings between grounds ranging from 250 to 320 feet (Figure 9) experience only about two tripouts per 100 miles of line per year when an average ground resistance of ten ohms is provided. The same degree of protection is shown to be provided by lines with one protector tube on the ridge-pole conductor of every other pole of lines with average spans of about 200 feet (Figure 10) if the same insulation level is provided. The performance record of a line with flat construction (Figure 10) having one tube per pole on alternate phases shows the importance of obtaining a reasonably high insulation level for unprotected phases at each pole. This line shows an outage rate of 43 tripouts per 100 miles of line per year, whereas the use of three tubes per pole on every third pole should result in only about four tripouts per 100 miles of line per year when the full insulation level of the unprotected poles is maintained.

Data have been obtained on the surge discharge duty of deion protector tubes installed continuously on protected lines and at isolated points on lines. For the former case the discharge rate for lightning surges is about 0.35 per individual tube per year, while the frequency of power-fault interruptions is only about 0.17 per individual tube per year. The corresponding rates of discharge are much higher for isolated tube installations. Likewise, the crest magnitudes of the surges that must be discharged at isolated installations are much greater.

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Control of Load, Frequency, and Time of Interconnected Systems

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MEMBER AIEE

Synopsis: The general problem is stated and typical solutions indicated. Characteristics of governors and of frequency- and load-control devices are briefly explained, and effects on generator and tie-line loads are summarized. Illustrating the principles enunciated, interconnected systems in southern Ontario and adjacent portions of Quebec totaling 1,650,000-kw generating capacity are described, also operating experience with automatic frequency control, and automatic load control of two ties, one of which is a 45,000-kw frequency-changer set interconnecting systems of relatively large capacity.

THIS IS the era of superpower. Two or three decades ago, engineers envisioned the day when the power resources of whole countries or even continents would be interconnected by vast networks of high-voltage transmission lines distributing electric power to all parts of the country. Today their dreams are approaching realization in large areas of the United States, in Britain,[6] and to a lesser degree in Canada and other countries.

On this continent these power networks or power pools as they are sometimes called, have grown up piecemeal by progressive interconnections within local areas, and finally by ties to more distant areas, which in turn may be connected to other areas beyond them. One of the earliest problems encountered in the operation of interconnected systems was the regulation of the transfer of power between one system and another, and closely related thereto, the regulation of frequency. A by-product of frequency control is time control, which demands precise *average* frequency, so that synchronous electric clocks may keep pace with the slow but inexorable advance of Father Time. These related problems are dealt with in this paper.

Purposes of Interconnection

At the outset, let us consider briefly the questions—why interconnection? and why control? Interconnections may be made for one or more of the following reasons:

1. Transfer of power from systems having a surplus to areas of shortage.
2. Diversity of loads on different systems.
3. Diversity of stream flow and storage facilities, affecting hydroelectric generation available in different areas.
4. Pooling of reserve generating facilities, with large savings in capital cost of stand-by generating capacity.
5. Greater reliability of service, and resources for emergencies.
6. Convenience in arranging outages of equipment for maintenance.

For example, water which would otherwise be spilled over the dam at some run-of-river plant might be used to permit storage of water at some other plant where storage facilities are available, which in effect transfers useable energy in the form of ponded water from one river to another which may be many miles distant; or alternatively, that water may be used to save expensive coal at some distant steam plant; or conversely, steam generation may be used to help out water-power areas in dry seasons. Diversity of loads and pooling of reserve capacity by interconnection make it possible to carry a greater total firm load on the combined systems than they could carry separately.

Control of some kind is necessary in order that the power transferred from one system to another over the interconnecting tie lines may conform to plans based on economic or contractual considerations. Tie-line load control is bound up with the control of frequency and time, since no one of the three may be changed without affecting the other two. Apart from their relation to load control, frequency and time demand close regulation on their own account; frequency, because many modern industrial processes with electric motor drives are dependent upon steady and accurate frequency; and time, because of the millions of electric clocks which time the movements of modern society to an accuracy measured in seconds. Some industries wish frequency to be controlled to a tolerance of plus or minus one quarter of one per cent on one-minute average values. This is not always attainable, but on the Southern Ontario system of the Hydro-Electric Power Commission of Ontario, that precision is attained for more than 98 per cent of the average day's run, using automatic frequency control. For the sake of electric clocks, the average frequency must be maintained even more precisely, since an error as small as 1/100 of one per cent will in 24 hours create a time deviation of eight seconds on electric clocks. Time on the Commission's Southern Ontario system is usually controlled more precisely than this, but emergency conditions and heavy war-time demands occasionally cause temporary time deviations up to five seconds and sometimes more. These errors are automatically corrected over a period of time after the emergency or overload condition has passed.

On interconnected systems, automatic frequency control is now almost universal, and automatic tie-line load control is becoming more and more extensively used. Where tie-line capacity or stability limits

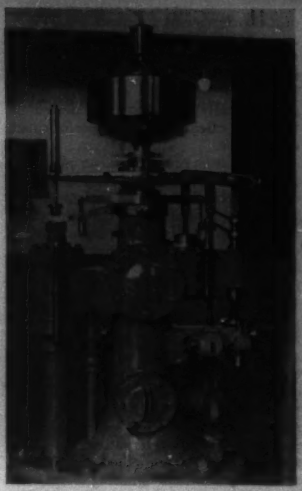

Figure 1. Governor of older type in use at Queenston plant

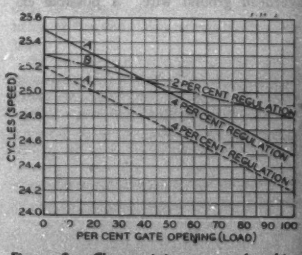

Figure 2. Characteristic curves of turbine governors, showing the relation between gate opening and speed

Paper 45-139, recommended by the AIEE committee on power generation for publication in AIEE TRANSACTIONS. Manuscript submitted December 1, 1944; made available for printing July 6, 1945.

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The author extends acknowledgments to the Hydro-Electric Power Commission for the use of illustrative material and to the editor of *Hydro News* for the use of photographs for Figures 11 and 15; also to the Gatineau Power Company for permission to publish information and to use photographs of equipment on their system.

are critical factors, automatic tie-line load control is essential for the maximum utilization of line capacity.

A recent article[13] describes an interesting example of interconnected systems in the northwestern states, where 11 important power systems in five states have a total of 3½ million kw generating capacity with 13,000 miles of major transmission lines ranging from 40 to 220 kv. This interconnection takes advantage of diversity of loads in two time zones and diversity of river flow in several watersheds on both sides of the Rocky Mountains, the resulting economies being equivalent to 100,000 kw of added generating capacity.

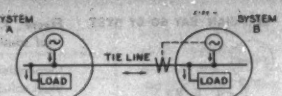
In this power pool we have examples of the two types of interconnection which are commonly met:

1. Systems connected like links of a chain, which may have side branches but no loops.
2. Multiple interconnections, forming loops.

One particularly complicated situation was solved by the unique method of phase-angle control,[3] but the usual problems were met by conventional methods of automatic frequency control and tie-line load control referred to later in the present paper.

Governor Characteristics

Regulation of frequency and tie-line load involves the regulation of the output of generators connected to the systems, and this requires regulation of the power input to their turbines. In a typical hydroelectric plant, the working fluid, water, is conducted from the forebay through the penstock to the turbine, and is discharged through the draft tube to the tail race. The discharge is controlled by the gates, consisting of a set of overlapping vanes arranged in a circle in the turbine casing at the point where the water enters the wheel. The gate stems pass through the upper wall of the turbine



1	2	3	4	5	6	7	8	9	10
LOAD CHANGE	FREQ	T.L.L. (1)	F.F.C. A (2)	T.L.L. (2)	F.T.L. B	T.L.B	SELEC. FREQ. A	SELEC. FREQ. B	T.L.L. (3)
+A	LOW	←	R	0	L(R)	L-R	R	—	0
+B	LOW	→	R	→	R	R	—	R	0
-A	HIGH	→	L	0	R(L)	R-L	L	—	0
-B	HIGH	←	L	←	L	L	—	L	0

T.L.L.=TIE-LINE LOAD. F.T.L.=FLAT TIE-LINE LOAD CONTROL. F.F.C.=FLAT FREQUENCY CONTROL. T.L.B.=TIE-LINE BIAS CONTROL. S.F.(COL. 8,9)=SELECTIVE FREQUENCY CONTROL. R=RAISING, L=LOWERING (ADJUSTMENT TO GOVERNORS).

Figure 4. Schematic diagram of two systems interconnected by a single tie line

Tabulation shows effect of load change on frequency and tie-line load due to governor droop characteristics only (columns 1, 2, and 3), followed by the effect of flat frequency control only on system *A* (columns 4 and 5); same plus flat tie-line control on *B* (column 6), or tie-line bias control on *B* (column 7); or selective frequency control on *A* and *B* (columns 8 and 9)

casing and all are connected to a gate ring, which is moved by servo-motor pistons under control of the governor.

Figure 1 shows one of the governors of the Queenston plant—not of the most modern make, but well adapted to an explanation of its operation, because its principal parts are large and exposed to view. The flyballs are on a vertical shaft, belted to the main generator shaft. The balls fly outward with increasing speed of the unit, and in so doing they raise a collar to which the center of the floating lever is coupled by a sliding shoe. The left end of the floating lever is connected to the pilot valve, which controls the turbine gates through the medium of the servo motor. The right end of the floating lever is positioned by a rod coming back from the gates. This mechanical construction determines a fixed relation between the steady-state speed and gate opening, which is called the speed-droop characteristic of the governor.

One other feature which should be noticed is the handwheel at the lower right and near it a small motor, called the synchronizing motor, which is geared to the handwheel. The synchronizing motor is used by the operator when starting the unit to adjust the generator to the proper speed for synchronizing to the bus, and after synchronizing, the same motor is used for adjusting load on the unit, or for regulating frequency of the system.

Automatic load or frequency regulators act through the medium of governor synchronizing motors. A change in the governor speed setting by means of this motor has the same effect as lengthening or shortening the gate return rod, causing a change in the speed associated with a given gate opening.

The relation between speed and gate opening is shown graphically in Figure 2 by the speed-droop curves of a governor. The base line is actually gate opening, starting from the no-load gate opening as zero, but it can also represent output or load on the unit, assuming that output is directly proportional to gate opening. This is not usually the case, but it will simplify our explanations to assume that it is true, and that our base represents per cent of full gate or per cent of full load.

As applied to a single isolated generator, curve *A* means that at no load, the frequency will be 25.5 cycles per second (hereinafter usually abbreviated to "cycles"). As load increases, the governor holds a lower frequency, which at

Figure 5. Fluctuating load on two frequency-changer sets in parallel constituting the tie between the Georgian Bay 60-cycle system and Niagara 25-cycle system

Frequency was manually controlled on the Niagara system and the frequency-changer load was unregulated

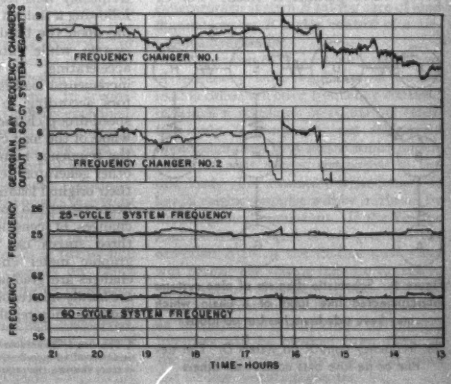
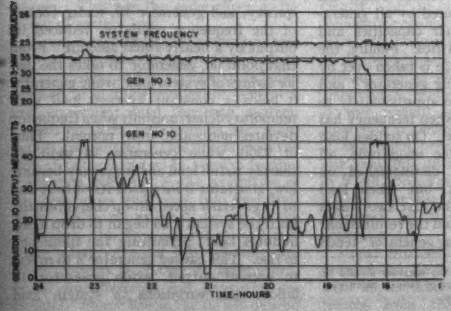


Figure 3. Frequency, and load of two Queenston generators, one (number 10) controlled by a frequency regulator and the other (number 3) on free governor control



half load will be 25 cycles. Further increase in load causes further reduction in speed, till at full load the frequency is 24.5 cycles—a total droop from no load to full load of one cycle on 25, or four-per-cent regulation.

When generators are operating in parallel, as on interconnected systems, frequency is the same for all generators, no matter whether they are side by side in the same generating station, or miles apart in different stations. Hence this speed-droop characteristic provides a basis for load sharing among generators operating in parallel, for example, two generators having speed-droop curves like *A* and *B* in Figure 2. All may not have the same per-cent regulation or the same full-load capacity, and these factors will affect the amount of any system load change which will be taken by each generator; but the main point is that generators in parallel tend to share all changes in system load due to their governor speed-droop characteristics, provided that no changes are made to the governor speed settings.

Effects of Frequency Control

In the early days of electric power, when frequency was not so important as it is now, the governor speed-droop characteristic was satisfactory, both for its main purpose as a basis of stable load sharing, and also for a crude sort of frequency control. Now, when frequency must be precisely controlled, the governors must be adjusted from time to time to compensate for changes in system load. Instead of making simultaneous equal adjustments to governors of all generators on the system, it is more convenient to adjust one or a few large generators, which are called the frequency-regulating generators of the system.

The effect of making an adjustment to the speed setting of a governor by means of the synchronizing motor shown in Figure 1 is to raise or lower the speed-droop curve parallel to itself. For example, curve *A* may be lowered to A_1, which would reduce the output of generator *A* and lower the frequency of the system. If frequency of the system is being regulated by adjustments to generator *A*, with no adjustments to generator *B*, then generator *A* will be compelled to take care of all load changes of the system, because when frequency is restored to 25 cycles, generator *B* will always be at the 60-per-cent load point. In other words, frequency control has the effect of counteracting the speed droop of generators to which it is applied—not eliminating the drooping characteristic, but shifting it to a new level after each load change.

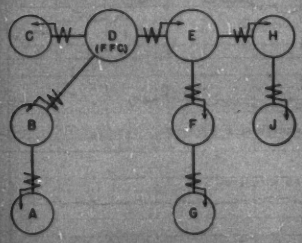


Figure 6. Schematic diagram of nine systems interconnected like links of a chain which may have side branches but no loops

Flat frequency control on system *D*. Flat tie-line or tie-line bias control on others

When load change occurs suddenly, there are three stages in the restoration of normal frequency. In the first stage, inertia of the generator and of other rotating machinery connected to the system is the governing factor, and so the frequency falls for the first few seconds following a sudden increase of load, drawing upon the total kinetic energy of the system, while water in the penstocks is accelerating. In the second stage, the incremental load is shared by all generators according to their capacities and speed-droop characteristics. Finally, the whole of the load change is taken over by the frequency-regulating generator,* and other generators return approximately to their original loading when frequency has been restored to normal. On sudden load changes of considerable magnitude, all three stages can be distinguished on graphic meter charts, but when load changes are gradual, the first two stages are hardly noticeable, and the result is that the frequency-regulating generator* tends to vary its output with all changes in system load, while other generators maintain approximately constant output.

This is illustrated in Figure 3.

Time runs from right to left. The lower curve shows the fluctuating load on generator 10 at Queenston when it was being used as a frequency-regulating generator for the Niagara system, with automatic frequency control. A little before 1800, a sharp increase in system load depressed the frequency temporarily and caused the output to increase to full load, in response to raising impulses from the frequency regulator. The frequency was slightly low for 20 minutes until 1815 when generator 3 was loaded to about 85 per cent of its maximum capacity by manual control. This raised the frequency, and generator 10, under control of the frequency regulator, reduced its output by a nearly equal amount. From that point on, generator 10 takes the major swings of system load, while generator 3 holds a constant average load with temporary departures only when frequency deviates noticeably from normal. Thus at 2300, when generator 10 went up sharply to full load and frequency became low, generator 3 increased its output due to its governor speed-droop characteristic, until the system load began to drop a few minutes later, permitting the frequency to rise. This caused generator 3 to revert to normal output, while generator 10 follows the variations of system load

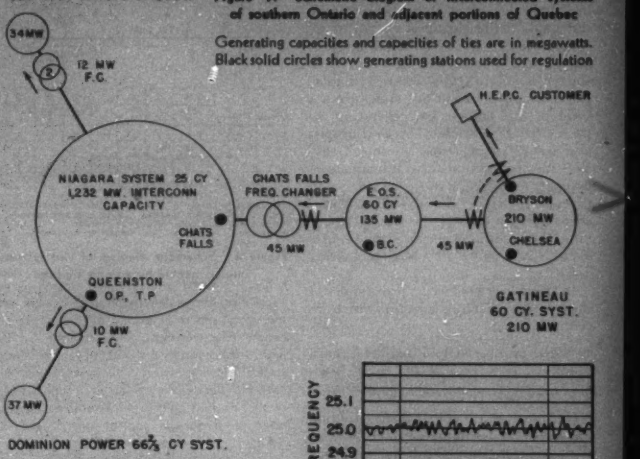


Figure 7. Schematic diagram of interconnected systems of southern Ontario and adjacent portions of Quebec

Generating capacities and capacities of ties are in megawatts. Black solid circles show generating stations used for regulation

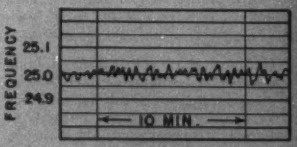


Figure 8. Uncontrollable fluctuations of Niagara system frequency (1936) showing irregular swings with a period averaging about 25 seconds

* The word "generator" in the singular should be understood to include the case of two or more generators sharing the regulation.

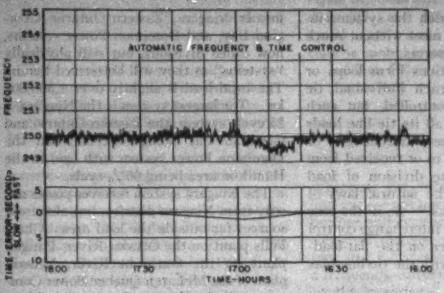


Figure 9. Automatically regulated frequency and time error of Niagara system (interconnected as in Figure 7)

Low frequency between 1640 and 1700 is due to regulating generators being at full load. Time lost owing to low frequency is later regained by automatic bias holding frequency slightly high from 1700 to 1725

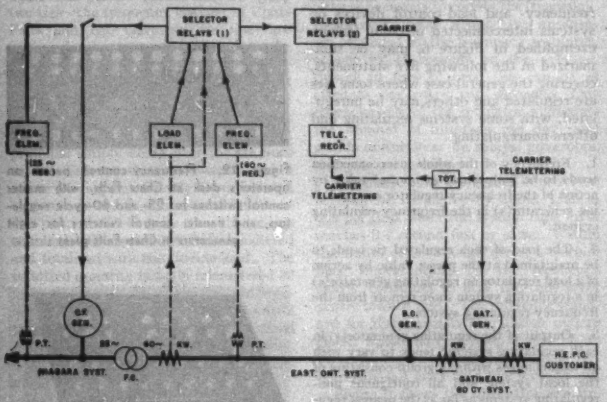


Figure 10. Schematic diagram of frequency- and load-control system centered at Chats Falls

Power circuits are in heavy lines, governor control circuits in light full lines, and metering circuits in broken lines

under control of the frequency regulator. The cause of the load increase on generator 10 at 2300 was reduction of generation at a base load plant elsewhere on the system. This has the same effect as increase of system load.

Figure 4 represents two power systems with an interconnecting tie line, numerous generators and numerous loads being reduced to a single equivalent generator and equivalent load for each system. Circuit breakers, transformers, and other details are omitted. This differs from the case of two generators in paral'el feeding a common load only in the separation of the generators and loads into two divisions. With no external control of the governors, the two generators will still share all incremental load of the combined systems, according to their speed-droop characteristics and generating capacities. Power flow in the tie will depend upon these two factors and also upon the origin of the load change—whether the change occurred in area *A* or in area *B*. For example, if load increases in system *A*, frequency will become low, and tie-line load will deviate in the direction *B* to *A*.

In a consideration of regulation of frequency of these systems, it is usual to make one system responsible for the regulation of frequency and time. This will usually be the larger system, or the one having greater generating reserves, or ability to handle load swings more efficiently. Let us choose system *A* as the frequency-regulating system. In accordance with the principles already explained, all changes in total load of both systems will appear as changes in the load of generator *A*, while the load of generator *B* will remain substantially constant. Therefore, if load change occurs in system *A*, it will not permanently affect the tie-line load, but all load changes occurring in *B* will appear as changes in the tie-line loading, because the changes are being absorbed by the frequency-regulating generator *A*.

Under the conditions just considered, unregulated tie-line loads tend to vary with all fluctuations in load of systems remote from the frequency-regulating system. This is illustrated in Figure 5, which shows load fluctuations on an unregulated tie consisting of two frequency changers in parallel, interconnecting two systems of the Hydro-Electric Power Commission in southern Ontario, the Niagara 25-cycle system, and the Georgian Bay 60-cycle system. The power flow is all in one direction, toward the 60-cycle system, which was deficient in stream flow and was receiving assistance from the Niagara system. One machine alone was on at first, and then two in parallel. At 1615, when the load on the frequency-changers was high, a sudden loss of load on the Niagara system caused the frequency to rise suddenly, and forced extra power through the frequency-changers to accelerate the 60-cycle system. This tripped off the already heavily loaded machines and the systems separated, Niagara frequency rising due to the loss of load, and Georgian Bay frequency dropping due to the loss of supply from Niagara. The drop of 60-cycle frequency was great because most of the generators on the Georgian Bay system were blocked and could not increase their output until the operators raised the blocks. The systems were paralleled again a few minutes later. The frequency here was manually controlled, which accounts for sustained deviations up to 0.3 cycle on 25 cycles.

Tie-Line Load Control

In many cases it is necessary to regulate the interchange of power through a tie line, holding the tie-line load substantially constant at a predetermined value. Referring again to Figure 4, when system *A* is regulating frequency, tie-line load may be regulated by control of generation in system *B*. A regulator sensitive only to tie-line load exerts what is called "flat tie-line load control." This tends to make each system "mind its own business," the generators in system *A* taking care of load fluctuations in that system under control of the frequency regulator, and generators in system *B* taking care of load fluctuations in *B* under control of a tie-line load regulator.

Another means of combining regulation of frequency with regulation of tie-line load is called selective frequency control,[4] in which a regulator or regulators sensitive only to frequency act selectively upon generators in *A* and *B* under supervision of watt relays, responsive to tie-line load. For example, if frequency is low, a raising impulse will be initiated by the frequency regulators. If the tie-line load at that instant is too great in the direction *B* to *A*, the tie-line watt relay will permit the raising impulse to pass to the governors of system *A*, since this will tend to correct the tie-line loading as well as to correct the frequency, but raising impulses will be blocked from going to the governors of *B*, since this would make the tie-line deviation greater.

When systems are connected like links of a chain, which may have side branches, but no loops, it is usual to assign frequency control to one large central system such as *D* in Figure 6, and have other systems regulate load in the tie leading toward the frequency-regulating system. This is simply an extension of the principle of load control on a tie line between two systems as already explained. If any system such as *F* is unable for any reason to regulate load in the tie between *F* and *E*, the tie *F–E* will become an unregulated tie, and system *E* will automatically assume the regulation for the two systems *E* and *F*, holding load on tie *E–D*

Figure 11. View in Chats Falls control room showing frequency-control supervisory panel switches on operator's desk

Round dial at left indicates total 60-cycle delivery from Gatineau Power Company, with load-setting controls in upper part of indicator case

up to the limit of the available generating capacity in system *E*. An overload on system *E* would make it impossible further to control the load in tie *E–D*, and would throw additional burden on the frequency-regulating system *D*.

On large interconnections it is usually desirable to provide for automatic assistance to the frequency-regulating system on the occurrence of unexpected overloads or emergency conditions. For this purpose it is customary to use tie-line load regulators in which the load setting is automatically biased by deviations in frequency, and perhaps also by time error.[7] This is known as "tie-line load control biased by frequency," abbreviated to "tie-line bias control." This system of mutual aid enables interconnections of vast magnitude to operate successfully, meeting demands which the systems individually could not meet without much greater generating reserves.

When interconnections form loops or networks, load on each individual tie cannot readily be controlled, but each system may totalize all its tie-line loads and regulate the "net interchange" or total power supplied to or received from the pool, leaving the division of load among the ties to the natural laws of power flow in networks.[12] As in the case of single tie lines, net-interchange control may be applied either on the flat-load-control principle, or with the tie-line-bias modification.

The characteristic effects of automatic frequency- and load-control devices on systems interconnected in chain fashion exemplified in Figure 6, may be summarized in the following five statements, covering the general case where some ties are regulated and others may be unregulated, with some systems regulating and others nonregulating.

1. Frequency of the whole interconnection tends to be maintained at normal value by action of the frequency regulator on regulating generator(s) in the frequency-regulating system.*

2. The load of each regulated tie tends to be maintained at the preset value by action of a load regulator on regulating generator(s) in a regulating system more remote from the frequency-regulating system.

3. Output of the regulating generator(s) in each regulating system* tends to vary with all load changes within a group consisting of the local system and all contiguous nonregulating systems as far as the nearest regulated ties.

4. Load of each unregulated tie tends to vary with all load changes of contiguous nonregulating systems of the group (as defined in 3) on the side of the tie remote from the regulating system of the group.

5. The output of generators other than regulating generators tends to remain approximately constant.

Interconnections in Ontario and Quebec

In Canada, the largest interconnection of power systems is in the province of Quebec, where three large systems operate with interconnected generating capacity of about 2,000,000 kw (1942). Frequency is regulated automatically by either of two of these systems, but automatic tie-line control is not used because of the long distances between load metering points and the generating stations, making installations difficult and expensive.[11]

Next in magnitude is the Southern Ontario system of the Hydro-Electric Power Commission of Ontario which is the product of the amalgamation of the former Niagara, Eastern Ontario, Georgian Bay, and Dominion Power systems, now called divisions, but still physically "systems" as they will be termed herein. The total load is slightly over 1,500,000 kw. The largest system is the Niagara, a 25-cycle system, the Eastern Ontario and Georgian Bay being 60-cycle, and the Dominion Power system with load in the Hamilton area being $66^2/_3$-cycle.

The Niagara system receives power not only from Niagara district, but also from sources far outside the load area: Chats Falls plant on the Ottawa River, Paugan plant on the Gatineau River, Masson plant of the McLaren-Quebec Power Company on the Lievre River, and Beauharnois on the St. Lawrence.[8,9] Each of the other systems is connected to the Niagara system through one or two frequency-changer sets. The single frequency-changer set for the $66^2/_3$-cycle system is located at Niagara Falls; for the Georgian Bay system, two sets at Hanover, at the end of a 110-kv 25-cycle line from Kitchener; and for the Eastern Ontario system, one set at Chats Falls plant. Generation on the Eastern Ontario system is supplemented by power from High Falls plant on the Lievre River, and from the Gatineau Power Company's 60-cycle system, both in the Province of Quebec. Tie lines interconnecting the Eastern Ontario system and Gatineau 60-cycle system cross the Ottawa River at a point just above the city of Ottawa.

These four systems of the Commission

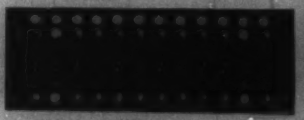


Figure 12. Frequency-control panel on operator's desk at Chats Falls, with master control switches for 25- and 60-cycle regulators, and transfer control switches for eight generators in Chats Falls plant

Figure 13. Load-control supervisory cabinet on operator's desk at Chats Falls, with switches and lamp indications for all load-control functions

* "Regulating system" is a general term which includes "frequency-regulating system" as a special case.

and the Gatineau 60-cycle system operate normally interconnected, with total connected generating capacity of about 1,650,000 kw.

Figure 7 shows schematically the five interconnected systems with the generating capacity in each system and the capacity of the ties indicated in megawatts. The normal direction of power flow is shown by the arrows. Flat frequency control with automatic time-error correction is maintained on the Niagara system by regulation at one of two points, Queenston plant on the Niagara River, or Chats Falls plant on the Ottawa River. The Georgian Bay and Dominion Power system frequency-changer ties are floating without automatic regulation. The other two ties—the frequency changer at Chats Falls and the Gatineau tie line—are equipped for automatic regulation, the first because of limited capacity of the frequency-changer set, and the second because of contractual obligations. The Gatineau Power Company delivers power to the Commission at two points, the principal supply being over the tie lines to the Eastern Ontario system, and a minor portion fed directly to an isolated customer of the Commission and metered at a point about 45 miles from the tie-line terminal. The isolated load is telemetered and totalized with the tie-line load. The totalized quantity is again telemetered 30 miles to Chats Falls where the load-regulating equipment is located. Control therefore may be applied to the totalized quantity rather than to the tie line only. Telephone-line carrier is used for telemetering and control.

Frequency-Regulator Characteristics

The type of frequency-regulating equipment in use at Queenston and Chats Falls was designed at the School of Engineering Research of the University of Toronto, under the supervision of H. W. Price, and all regulators were built in the Commission's shops. The initial installation at Queenston has been in service since 1934, and two regulators—one 25-cycle and one 60-cycle—have been in service at Chats Falls since 1942.

In a preliminary study of Niagara system frequency and governor characteristics, it was observed as shown in Figure 8 that frequency of a large system is continually fluctuating with an irregular period averaging about 25 seconds, even when the system load is relatively steady. These swings are too rapid to be controlled, and too small to be of vital consequence when they are of short duration. Therefore, the frequency regulator was designed to disregard these minor fluctuations, but to be very sensitive to deviations in average frequency. The regulator maintains a close comparison between total integrated cycles of system frequency and the nominal cycles corresponding to rated frequency of the system.

Figure 14. Time-error dials (25- and 60-cycle) and station clock in control room at Chats Falls

Whenever the difference changes by one half cycle—not one half cycle per second, but one half cycle in phase position, or 180 electrical degrees—on the 25-cycle system, or 1.2 cycles on the 60-cycle system, a frequency-corrective impulse is sent out to the governors. This is repeated as often as necessary to correct the frequency. In the average day, about 2,000 impulses are produced by the frequency regulator, or one in 45 seconds on the average, though in time of need this can be as often as one every two seconds. This characteristic of the regulator minimizes the number of impulses per day, and avoids undue wear on relays, governors, and gate mechanisms.

Automatic time correction is provided to bias the frequency by about 1/20 of one per cent when the system time error reaches 0.4 second fast or slow. Within the limits of 0.4 second error, a vernier bias, imperceptible on the frequency charts, continues to urge the time error gently toward zero. The reference standard for time error is the station master clock, which may develop errors of its own with regard to radio time signals, but is usually not more than five seconds out.

Figure 9 shows the uncontrollable frequency fluctuation at a slower chart speed. It also shows a frequency dip resulting from overload on the regulating unit, and the resulting time error; then after relief from overload, the automatic frequency bias, just perceptible as a change in the average level of the frequency line, and finally restoration of normal average frequency when the time error is less than 0.4 second.

Scheme of Frequency and Load Control

Figure 10 is a schematic diagram showing the essential elements of the scheme of combined frequency and load control from the 60-cycle control equipment centered at Chats Falls. Corrective impulses may be initiated either by the frequency-sensitive element, supplied from 60-cycle potential, or from the load-sensitive element, responsive to load measured on the 60-cycle side of the frequency-changer set. These impulses, from both sources, are sorted by the first set of selector relays, raising impulses being sent to 25-cycle generators in Chats Falls plant and lowering impulses toward 60-cycle generators, or vice-versa, depending upon the direction of the existing deviation of frequency-changer load from the scheduled value as set on a watt relay. Impulses which are directed toward 60-cycle generators must now pass a second set of selector relays, which determine on the basis of the total Gatineau delivery, totalized and telemetered back to Chats Falls, whether raising impulses should be permitted to go to Gatineau plants and lowering impulses to Barrett Chute, or vice-versa.

Figure 15. Telephone-line carrier transmitting and receiving equipment for telemetering and remote control at Chats Falls

Figure 16. Telemetering and load-control panel in control room at Bryson plant of Gatineau Power Company

The principle of this control system is a combination of selective frequency control and flat tie-line load control. The frequency-sensitive element, initiating impulses on the basis of frequency deviation only, and the selector relays, distributing these impulses on the basis of deviations in the tie-line loads, embody the principles of selective frequency control. This control alone is prompt in regulation of frequency, and also has a tie-line load-regulating effect, but is rather slow in shifting load after a change in setting of the watt relay, because impulses are initiated only by random swings of frequency. Selective frequency control is therefore supplemented by load-regulating impulses initiated by the load-sensitive element, re-

gardless of frequency. All the impulses from the load element go to 60-cycle generators, either Barrett Chute or Gatineau. Impulses from the load element are sent at either of two rates, once every 6½ seconds for deviations exceeding 5,000 kw or once every 20 seconds for smaller deviations. The combination of a 20-second time interval with a suitable dead band on the watt relay gives the regulating generators time to respond to each impulse, and gives stable operation. The watt relay is designed to be insensitive to the rapid swings of synchronizing power which are typical of tie-line loads, but to be sensitive to sustained deviations in either direction.

Figure 11 is a view of part of Chats Falls control room showing the large dial on which the Gatineau 60-cycle delivery is indicated. Adjustable contacts in this instrument are used to set any desired delivery. In front of the farther operator is the control panel for supervision of the 25- and 60-cycle frequency regulators, and for the eight generating units in this plant. At his left and hidden from view is a control cabinet for supervision of the load regulator.

Chats Falls frequency regulator and generator control panel is shown in Figure 12. Master control keys for the two frequency regulators are at the extreme ends of this panel, 25-cycle at the right and 60-cycle at the left. The 60-cycle regulator is always in use, and the 25-cycle regulator is also required when the systems are separated. With the systems separated, Chats Falls generators may be transferred to the 25-cycle regulator as suggested in Figure 10. Next to each master key is the frequency bias key for automatic time correction. This key is "on" except when Queenston is regulating frequency and time. The other eight keys are for placing the eight Chats Falls units on automatic control, from the 60-cycle regulator if the keys are up, or from the 25-cycle regulator if the keys are down. Lamps indicate the position of the keys, and other lamps (upper row) indicate when the units are approaching full gate, which is their limit of control. Limit switches on the governor prevent the automatic control from raising the units above 90 per cent gate or lowering below 50 per cent, in order to keep them in a fairly efficient operating range.

Figure 13 shows Chats Falls load control supervisory cabinet. This cabinet, located on the operator's desk, is for control and supervision of the 60-cycle frequency and load regulation centered at Chats Falls. Indicating lamps show where each impulse goes—to Chats Falls generators, to Barrett Chute, or to Gatineau generators—and whether it is a raising or a lowering impulse. Lamps also indicate whether the tie-line loads are above or below the scheduled setting, and a special red lamp and intermittent buzzer signal draw the operator's attention when the frequency-changer load deviates more than 5,000 kw from schedule. The switches may be used to set up the control for abnormal operating conditions. For instance, when the frequency changer is out of service for maintenance, thus separating the 25- and 60-cycle systems, Chats Falls units are taken off the 60-cycle control, and the 60-cycle regulator is then used for regulation of 60-cycle generators only. This change in control setup also takes place automatically when the frequency changer trips off for any reason, and the change is indicated by a red lamp signal. Other lamps are for supervision of the three carrier sets, two transmitters and one receiver, which may be seen in Figure 15.

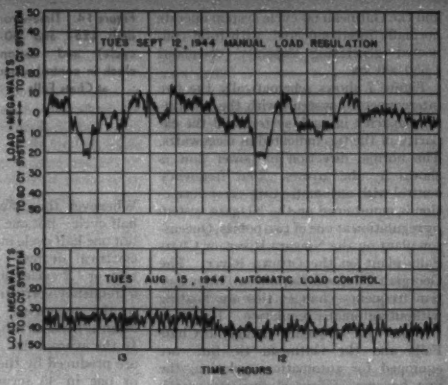


Figure 17. Comparison of load on Chats Falls frequency-changer set with and without automatic control

The clock case shown in Figure 14 is mounted above the switchboard in front of the operator's desk in Chats Falls control room. The two outer dials are time error indicators, 25- and 60-cycle respectively, and the center one is a time clock operated electrically by impulses at half-minute intervals from the station master clock which is checked daily by radio time signals. The large time-error dial covers a range of 1½ seconds fast or slow, and a smaller inset dial goes to 12 seconds fast or slow. These indicators operate by position-type telemeter system, from the time-error element of the frequency regulators. When the systems are interconnected both dials read alike, and normally not more than one half second fast or slow. Time-error recorders give a graphic record on a chart with range of 25 seconds fast or slow, which is rarely overrun even in times of serious trouble. The ordinary range of time deviations during present conditions is from five seconds fast to five seconds slow, which is due to shortage of spinning reserve because of war loads. The reference standard, as already stated, is the station master clock.

Figure 15 shows telemetering and load-control carrier terminal equipment at Chats Falls. This consists of two carrier transmitters on the nearest panel, one transmitting to Barrett Chute and one to Gatineau plants, and one receiver on the lower part of the second rack, receiving telemetering signals representing Gatineau total 60-cycle delivery. This equipment is located at the terminals of the open-wire telephone circuits on which the carrier is superimposed on audio-frequency voice communication.

The telemetering transmitter and load control panel at Bryson is shown in Figure 16. A carrier receiver, connected to the telephone line, brings in load-regulating impulses to the relays on this panel, and these in turn operate on the governors. At the same time, the telemetering transmitter, measuring the local delivery to the Commission, is sending out telemetering signals on the same telephone line at a different frequency. Indicating lamps and buzzer give all necessary indications and warnings. The instrument at the top of the panel is a frequency relay which is intended to block the incoming control signals from Chats Falls in case of a separation between the Eastern Ontario and Gatineau systems. If such a separation should occur the Gatineau frequency would rise, closing a high-frequency contact of the frequency relay and locking out the automatic control until reset by the operator. Except for the telemeter transmitter, this equipment is typical of the installations at each of the three remote generating stations.

Operating Performance

Figure 17 shows the comparison between automatic and manual control of frequency-changer load at Chats Falls. The noon hour was picked as the time when load changes occur at the greatest rates on both 25- and 60-cycle systems and when load swings are likely to be severe. Manual control was considered permissible only because the desired transfer was about zero, and swings would not likely overload the set, if watched. An operator was assigned to watch the load

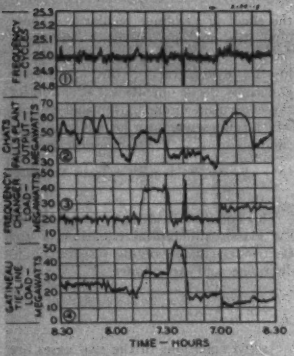


Figure 18. Charts showing results of automatic frequency and load control during trouble conditions on Eastern Ontario system

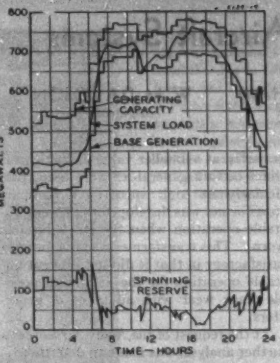


Figure 19. Daily load curve for a portion of the Niagara system, showing total connected generating capacity, base load generation, and spinning reserve, based on half-hourly readings

Thursday November 6, 1941

throughout this period and to telephone for correction of 60-cycle generation when required. With automatic control, the set carries as much as 40,000 kw average load at any time it is required with little or no attention on the part of the operator and rarely a telephone call for load correction. The chart shows a change in the load setting from 40,000 kw to 35,000 kw at 1225, an operation which is quickly and easily performed by a setting on the watt relay. The load responds promptly to this.

The capacity of this frequency-changer set is 45,000 kw which is about 13 per cent of the connected generating capacity of the 60-cycle systems. During two years of interconnected operation it has tripped off and separated the systems 13 times, ten of these separations being due to severe disturbances on one or both systems, and the other three due to overload occasioned by lack of experience in interconnected operation during the first year. The set has withstood surprisingly large disturbances without tripping, but on these occasions the initial load on the set happened to be small, or was in such a direction that the disturbance reduced or reversed the direction of the power flow.

Figure 18 illustrates the behavior of the control system and the interconnected generators during trouble. Generators at High Falls supplying 35,000 kw to the Eastern Ontario system suddenly tripped off. The meter charts shown are:

1. Twenty-five-cycle system frequency.

2. Output of Chats Falls plant, which was being used as the regulating station for the Niagara system.

3. Chats Falls frequency-changer load, which was being regulated by the automatic load regulator, acting on Gatineau 60-cycle generators.

4. Gatineau tie-line load, which was not being regulated at the time because Barrett Chute plant was shut down and was therefore not available for regulation.

Under these conditions it is to be expected that the Gatineau tie-line load will fluctuate with all changes in load or generation in the Eastern Ontario system, since the only 60-cycle generators available for regulation were in the Gatineau system.

At 7:19 p.m., when the 60-cycle generators at High Falls tripped off, depriving the Eastern Ontario system of their 35,000 kw generation, the frequency suddenly dropped to 24.8 cycles on the 25-cycle system, and by a corresponding amount on the 60-cycle systems, but quickly recovered to 24.95 cycles approximately, and finally to 25 cycles in about three minutes. It is apparent that the sudden change in load was carried initially by the kinetic energy of the system while frequency was dropping during the first few seconds, then was shared by both 25- and 60-cycle generators because of their speed-droop characteristics, and finally was absorbed by the regulating generator of the 60-cycle systems. The swing of 25,000 kw in the frequency-changer load is the share of the load change which was contributed temporarily by the 25-cycle system, a small part (5,000 kw) coming from Chats Falls generators, and the balance, or 20,000 kw, from other generators, at Queenston and elsewhere. The other 10,000 kw came from the Gatineau generators, as shown by the initial rise in the lower curve. The automatic regulator immediately began to send raising impulses to Gatineau generators, in an effort to raise the low frequency and also to correct the deviation in the frequency-changer load. This was accomplished in three minutes, when the frequency-changer chart shows its load was back to schedule at 7:22, and the whole of the 35,000 kw lost generation was made up by the Gatineau generators. Notice that Chats Falls output returned to its original value. This shows how sudden load change is shared initially by all generators having any spinning reserve, but is absorbed ultimately by regulating generators in the system or group where the disturbance originated.

Although the automatic load control had successfully performed its function in relation to the frequency-changer load, the effect was to increase the Gatineau 60-cycle delivery above the contract amount. Since Chats Falls generators had spinning reserve capacity available, the load setting on the frequency changer was manually changed at 7:27 from 20,000 kw to 40,000 kw toward the Eastern Ontario system. This increased Chats Falls output by 20,000 kw and reduced Gatineau output by a similar amount by 7:30 p.m. Finally, at 7:45, High Falls generators came back on load, and all conditions were restored to normal.

Automatic Controls and the Human Element

Although much can be said for automatic controls, it must be recognized that they have definite limitations. Automatic regulators do a job which human operators either cannot successfully perform, or can perform only by constant attention to an exacting and never-ending task. Nevertheless it should not be inferred that a system equipped with a few control devices at strategic points practically runs itself. Regulators can function only within the limits of capacity of the generators under their control, and this may be in the order of five to ten per cent of the total generating capacity of the system or group of systems for which these generators are regulating. The remaining generation, on base load, must be adjusted up or down from hour to hour to conform to the general trend of the system daily load curve as estimated by the power supervisor, so as to keep the regulating generators within their regulating range. This is illustrated by Figure 19 showing a 24-hour curve of connected capacity, load, and base load generation for a portion of the Niagara system. Load assignments are made partly by prearranged schedule, but the supervisor must be prepared at any moment to meet unforeseen conditions with such power resources as are available. For this purpose, automatic controls must be supplemented by adequate communication facilities, and by telemetering of critical quantities such as forebay levels, loads on ties, and loads on generating stations, especially those that are under control of automatic regulators.

Instability in D-C Aircraft Systems

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Synopsis: A laboratory and theoretical study was made to determine the causes and methods of combating an unstable oscillatory voltage condition which has been encountered in aircraft d-c electric systems, using types *P*-1, *P*-2, and *R*-1 generators with carbon-pile voltage regulators.

The generator characteristics were found to be such that oscillatory instability would not occur without the presence of a voltage regulator which was out of adjustment and which had inadequate damping.

A method is given for determining the amount of damping required for stable operation in terms of the generator field time constant and certain regulator characteristics.

INSTABILITY has been encountered in aircraft electric systems employing 28.5-volt generators, 24-volt batteries, and carbon-pile voltage regulators. In systems in which the regulators were out of adjustment, sudden application or removal of load has initiated sustained oscillations in load current and system voltage. The frequency of these oscillations has been between 10 and 60 cycles per second with amplitudes as large as the maximum value of load current.

In an analysis by the Army Air Forces it was determined that this type of system instability was associated with wear of the regulator stack and could be corrected by readjustment of the regulators. The analysis also disclosed that instability occurred at a smaller value of stack wear when certain generators were used, particularly at high speeds. A damping transformer was developed to prevent unstable operation when the stack became worn. This transformer was not entirely satisfactory in that it did not prevent unstable operation for the maximum possible stack wear with all types of generators.

At the request of the Army Air Forces a further analysis was made to determine

1. The causes and nature of the unstable condition.
2. A means of evaluating the generator and regulator characteristics to determine whether they tend to be unstable.
3. A means of preventing instability.

Generator Stability Analysis

The first approach was to determine whether a generator without a regulator could sustain an oscillation initiated by a switching transient.

Equivalent Circuit for Generator and Load

From the mathematical analysis given in Appendix II, it is possible to determine the relation of the electrical quantities and characteristics of the generator and load circuits which would be necessary to produce oscillatory instability without the effect of a voltage regulator. These quantities and characteristics were measured on a particular generator and used in the evaluation of the operational equations. The operational equation for the equivalent circuit, given in Figure 1, which relates generator load current with time is

$$(p^3+\alpha p+\beta)i_l = C \text{ (equation 11 of Appendix II)}^*$$

This equation is identical in form with the classic differential equation of the electric circuit involving resistance, inductance, and capacitance,

$$\frac{d^3i_l}{dt^3}+\alpha\frac{di_l}{dt}+\beta i_l = C$$

As the equations in the two cases are identical, there must, of course, be found in the solution of the former the same oscillations and transients as are contained in the well-known solution to the latter.

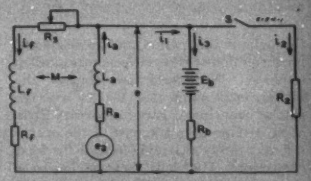

Figure 1. Equivalent circuit of generator with battery and resistance load

In Figure 1, although there is no condenser capacity involved and therefore no electrostatic energy, there are nevertheless two different magnetic circuits in which energy can be stored. During an oscillation all of the energy stored in the generator field cannot be transferred to the armature circuit. Most of it is dissipated as i^2r. One of the objects of this investigation is to determine whether the characteristics are such as to transfer enough energy between the field and armature circuits that oscillations may be produced. Such oscillations, although small and highly damped, might be amplified by the voltage regulator so as to produce subsequent oscillations.

Generator Characteristics

The generator characteristics necessary to evaluate the above operational equation were measured for *P*-1, *P*-2, and *R*-1 generators, with the test equipment shown in Figure 2. Values of r_f, L_f, L_a

Paper 45-154, recommended by the AIEE committee on air transportation for publication in AIEE Transactions. Manuscript submitted June 14, 1945; made available for printing August 1, 1945.

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* For explanation of symbols see Appendix I.

In conclusion, it is interesting to note that interconnection has developed a high degree of co-operation without which its fullest benefits would be unattainable. Operating staffs and managements of interconnected systems have learned that what is best for the whole is usually best for each. Best results are attained when all systems are prepared to contribute according to their ability, to meet the need of any—a principle which works well in all human relationships.

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Figure 2. General view of test equipment showing in left foreground special d-c drive motor used to obtain minimum speed regulation on sudden application of load to the aircraft generator

and field time constant for all types of generators are given in Table I.

Oscillatory Instability

In the solution of equation 11 it is found that the condition for no oscillation in the circuit containing generator, battery, and load is that existing when $\beta < \alpha^2/4$. With the characteristics of the *P*-1 generator of manufacturer *A* from Table I and the following:

Generator	Load
$M = -0.16$ millihenry	$E_b = 27.6$ volts
$R_a = 0.03$ ohm	$R_b = 0.028$ ohm
$r_f = 14.76$ ohms	$R_l = 0.57$ ohm
$Kk_a = 0.031$ volt per ampere	
$Kk_f = 12.0$ volts per ampere	
$e_r = 5.18$ volts	

it may be shown that the circuit is non-oscillatory. There is no value of Kk_a which can make the circuit oscillatory with the other parameters remaining the same as given above. However, with the initial value of Kk_a and a value of $M = -0.8$ millihenry, it can be shown by calculation that a damped oscillation of about six cycles per second theoretically could be produced. This value of M is five times the measured value for this generator. The brushes as set to give maximum output were about 1/4 bar behind neutral. It is possible that a similar generator with a larger brush shift might have a greater M, but it is not likely that it will approach 0.8 millihenry. Mutual inductance in a generator is a very difficult quantity to measure with accuracy.

Inasmuch as the *P*-1 generator of manufacturer *A* has shown the greatest tendency for unstable operation and its measured parameters were so far short of the values necessary to produce instability without a regulator, these equations were not evaluated for any other generator.

It is interesting to note that in all cases where oscillations may be produced it is necessary to have cumulative compounding (this does not imply overcompounding) with armature current; that is, a positive value for Kk_a. Practically, this will be obtained only with generators having series, interpole, or compensating windings and with brushes shifted against rotation, the cumulative compounding direction. Generators without interpole or compensating windings normally have their brushes shifted in the direction of rotation, because they do not commutate satisfactorily with brushes shifted against rotation. In the laboratory rising volt-ampere characteristics were obtained at maximum rated speed for *P*-1 generators of manufacturer *A*, which have interpole and compensating windings. In all cases it was necessary to have

1. Brushes set for maximum output.
2. Well-polished and well-seated brushes.
3. A black carbon film deposited on the commutator.

For generators without interpole or compensating windings volt-ampere output was increased by application of a film, thus indicating a cumulative effect. *P*-2 and *R*-1 generators exhibited the same compounding characteristics as the *P*-1 generator of manufacturer *A*, except that the film was more difficult to maintain at the maximum speed of 10,000 rpm.

A theoretical calculation and laboratory test were made to determine load current as a function of time for the generator of manufacturer *A* running at 4,500 rpm in parallel with a *G*-1 battery while switching a 50-ampere load. The circuit arrangement is shown in Figure 1. The generator and load characteristics are given in the foregoing table.

The calculated transient value of load current after switching load R_3 in parallel with the battery (battery previously floating on line) is

$$i_1 = -63.06e^{-1.19t} + 2.96e^{-179.1t} + 64 \text{ amperes}$$

At $t = 0.66$ second the load R_3 is switched off, and the calculated expression for load current becomes

$$i_1' = 62.9e^{-1.49t} - 2.8e^{-180t} + 3.9 \text{ amperes}$$

These expressions are plotted as a function of time in Figure 3. A comparison with data from an actual test oscillogram for the same generator and the same circuit conditions also is shown in Figure 3. Discrepancy between the test and calculated values is caused by variations in generator and load circuit parameters under operating conditions and by unavoidable inaccuracies in measurement of parameters. In the expression for load current it should be noted that there are no oscillatory terms.

It can be seen from the test curve that, although no oscillations were present, load current reversed, and the system became unstable. There was actually a reversal of polarity of the residual field in the generator each time this unstable operation occurred. This reversal of polarity probably is caused by the resultant armature, interpole, and compen-

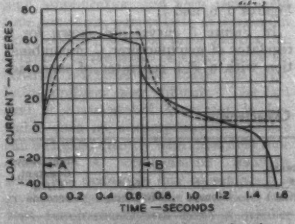

Figure 3. Comparison of calculated and test curves of load current as a function of time for switching a resistance load in parallel with a battery (*P*-1 generator, manufacturer *A*)

---- Calculated
——— Test oscillogram
A—Switch *S* closed
B—Switch *S* opened

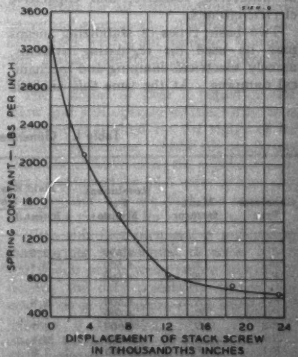

Figure 4. Spring constant versus stack displacement (regulator manufacturer *C*)

sating-winding flux overcoming the main-field-winding flux, as in a series motor with brush shift against rotation.

Although this latter phenomenon constitutes a form of instability, its action is sufficiently slow that a voltage regulator easily can prevent the voltage collapse. As all of the instability troubles recorded in service were oscillatory in nature, the analysis of this phenomenon was not pursued further.

Regulator Stability Analysis

Once it was found that the generator of manufacturer *A* without a regulator would not sustain an oscillation, the next approach was to determine what characteristics of carbon-pile regulators would produce instability in combination with generator characteristics.

A voltage regulator in any system behaves in a manner similar to an amplifier. Small deviations in the regulated voltage are made to produce relatively large changes in the generated voltage of the final machine to offset the internal voltage drop caused by variations in load. Such devices as vibrating contacts, motor-operated rheostats, and carbon-pile rheostats have been used to produce the large changes in excitation for small errors in the regulated voltage, and, although in some cases their action is intermittent, the net result produced has been amplification.

The chief difficulty in stabilizing all regulating systems is the presence of time delays. These may be analyzed in terms of the time constants of the various inductive circuits, such as the fields of rotating machines and also the time constants of the regulator itself. The latter may be electrical, mechanical, or both. Such a system may be idealized by showing the amplifier or regulator without delay but with an extra exciter to represent its delay, so that all the constants can be represented by simple inductive and resistive, or inductive, resistive, and capacitive electric circuits.

Two basic types of stabilizing means may be used for regulating systems, namely, electrical damping and mechanical damping. At the time this analysis was made no mechanical damper had been devised for aircraft carbon-pile regulators because of the difficulty of obtaining sufficient damping with the extremely small armature travel.

In this analysis a damping transformer was assumed to be the most satisfactory method of electrical damping. The problem then resolved into finding the correct size damping transformer to provide stable operation with all combinations of generators and regulators which would be used.

In Appendix III a mathematical analysis of the problem is given which includes all the characteristics of the system that have a major effect upon stability. Some of the constants for this system are difficult to measure, and a few assumptions are necessary, but from this analysis one can determine the approximate size damping transformer necessary for stable operation. Once the approximate amount of damping necessary is known, the optimum size damping transformer can be determined quickly from laboratory tests.

It had been shown in service and laboratory tests that wear or maladjustment of the carbon stack was the initiating cause of oscillatory instability. Decrease of the spring constant with increasing stack displacement, which is shown for a particular regulator in Figure 4, appears as an increase in the value of C_m in equation 30, Appendix III. This equation also shows that the value t_d $(=M/R_p)$ is the determining factor in the design of the damping transformer. Additional factors in the design of a damping transformer are discussed in another AIEE paper.[1]

Results of Calculations and Regulator Tests

Curves of stack displacement versus the value of M/R_p necessary to maintain stable operation for several generator and regulator combinations are shown in Figures 5, 6, and 7.

In Figure 5 curves are shown for a regulator of manufacturer *C* in combination with a *P*-1 generator of manufacturer *C*. This regulator was the earlier model containing no antihunt resistor. The test curve is plotted from points where stability was just maintained with the regulator at operating temperature. The calculated curve shows the value for critical* damping using the following constants in equation 30, Appendix III:

$R_e = 30$ ohms
$L_g = 0.0875$ henry
$R_m = 0$ and 0.1 pound-inch per second
$1/C_m$ = value obtained from Figure 4
$AR_e = 200$

The curves shown in Figure 6 are for the same regulator, manufacturer *C*, with a *P*-1 generator of manufacturer *A*.

The curves shown in Figure 7 are test curves taken with a regulator of manufacturer *B* in combination with a *P*-1 generator of manufacturer *A*. This regulator contained an antihunt resistor, and curves were taken with and without this resistor to illustrate its effect.

There can be noted a discrepancy of about two to one in the calculated and

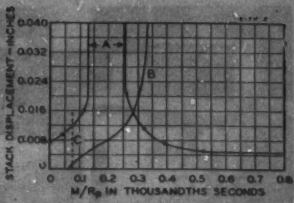

Figure 5. Distance stack screw can be moved out before instability occurs versus M/R_p of damping transformer (regulator manufacturer *C*, *P*-1 generator manufacturer *C*)

A—Test
B—Calculated (mechanical damping = 0)
C—Present transformer

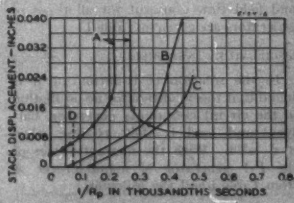

Figure 6. Distance stack screw can be moved out before instability occurs versus M/R_p of damping transformer (regulator manufacturer *C*, *P*-1 generator manufacturer *A*)

A—Test
B—Calculated (mechanical damping = 0.1 pound-inch per second)
C—Calculated (mechanical damping = 0)
D—Present transformer

Table I. Generator Characteristics

Generator Type	Manufacturer	Revolutions Per Minute	Field Resistance in Ohms R(gen.)	Field Resistance in Ohms r(fld.)	L_g,* Henrys	L_m,* Millihenrys	Field Time Constant, L_f/r_f, Seconds
P-1	*A*	4,500	2.3	14.0	0.28	0.14	0.020
P-1	*A*	4,500	2.4	16.3	0.20	0.14	0.013
P-1	*B*	4,500	2.8	20.0	0.36	0.22	0.018
				(calc. 0.28)			
P-1	*B*	4,500	3.8	18.0	0.33	0.23	0.018
P-1	*C*	4,500	2.9	16.5	0.51	0.19	0.031
P-2	*D*	8,000	2.7	14.0	0.22	0.10	0.016
R-1	*E*	10,000	2.6	20.0	0.27	0.08	0.013
R-1	*F*	10,000	2.8	20.0	0.43	0.07	0.021
M-2	*G*	2,500	3.0	20.0	0.53		0.036

* Inductance values obtained from oscillograph-ic measurements.

* For definition see Appendix III.

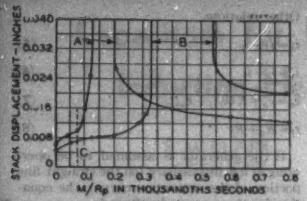

Figure 7. Distance stack screw can be moved out before instability occurs versus M/R_p of damping transformer (regulator manufacturer B, P-1 generator manufacturer A)

A—500 damping resistor
B—No damping resistor
C—Present transformer

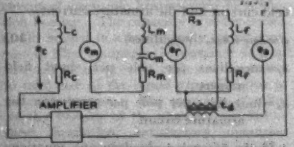

Figure 8. Representation of system with three time delays and one damping transformer

test values for the amount of damping required for a given stack displacement. This can be attributed to several factors. The measurement of the spring constant of the regulator was a tedious procedure, requiring observations of armature displacement in the order of 1/10,000 inch where a small error would be greatly magnified. Also the values of M/R_p for the test curve might be in small error because of interpolation from the inductance curves. The value of mechanical damping of 0.1 pound-inch per second was obtained from equation 30, Appendix III, using the spring constant for the stack position from the observed critical damping of the regulator with no damping transformer or antihunt resistor. The mechanical damping may be greater than this, which would make the calculated and test curves in closer agreement. There is no direct method of measuring the mechanical damping of this type regulator. It is also likely that the assumed amplification of 200 is higher than the actual value.

Test curves show that for a given transformer there is an upper limit to the value of M/R (obtained by decreasing R_p) which will provide stable operation. Although the feedback voltage (proportional to M/R_p) can be further increased by reducing R_p, the self-inductance in the primary winding (neglected in Appendix III) becomes appreciable and causes the feedback correction to lag the error voltage, so that the resultant damping is reduced. A lower limit for the value of R_p to give maximum feedback for effective damping with a given transformer, generator, and regulator combination could be obtained by solving a fifth-order equation. The practical way to obtain this limiting value is from test curves.

Conclusions

Factors Affecting Stability

Mutual Coupling in Generator. It is theoretically possible for an oscillatory condition to occur following a switching transient in a system composed of a generator (without voltage regulator), a battery, and a resistance load. The condition necessary to produce oscillation is large mutual coupling between the armature and shunt field windings. This coupling must be in the direction to produce cumulative compounding.

Cumulative Compounding in Generator. Generators having compensating and interpole windings and having the brushes shifted against rotation (in order to give maximum output) most nearly approach this condition. However, the measured constants of present *P*-1, *P*-2, and *R*-1 generators fall so far short of the values necessary to produce oscillatory instability (without a regulator) that the compounding tendency was concluded to be a secondary factor in the creation of an oscillatory condition.

Generators having rising volt-ampere characteristics may become unstable when operating with other generators or a battery. This is a nonoscillatory type of instability. This phenomenon was reproduced in the laboratory with a *P*-1 generator having compensating windings and a film on the commutator such as to give maximum compounding. However, this transient was so slow that the addition of a voltage regulator prevented occurrence of the phenomenon. This characteristic may tend to make the task of the voltage regulator more difficult but is again a secondary factor in the creation of system oscillations.

Time Constant of Generator Shunt Field. The aircraft generators investigated have high amplification and very small field time constants, particularly at maximum rated speed. Both of these factors are contrary to the usual case with large industrial machines and make the regulating problem more difficult. The fact that a compensated generator is less stable than an uncompensated machine can be linked directly with their field time constants. A compensated machine needs less main-pole flux to maintain a given voltage and for the same field current requirements will have a weaker shunt field winding with less inductance. This difference in inductance between machines is greater than the difference in total field resistance of the machines for no-load and light-load operating conditions, so that the compensated machine will have a smaller field time constant. The test and calculated curves in Figures 4 and 5 bear out this relationship. Both curves were made with the same regulator, but in Figure 5 the *P*-1 generator having the largest field time constant was used, whereas in Figure 6 the generator having the smallest field time constant was used. The use of interpole or series windings will have a similar effect.

Regulator Mechanical Construction and Assembly. The original assembly and adjustment of the regulator has a bearing on the amount of wear necessary to cause system instability. No two springs are identical, but the differences in individual springs should be maintained as small as possible by checking before assembly. This spring discrepancy and a noncritical final adjustment of the regulator can affect the amount of allowable stack wear by a thousandth of an inch or more. This is illustrated by comparison of the test curve in Figure 6 and the test curve without the antihunt resistor in Figure 7 at $M/R_p = 0$.

Regulator Antihunt Resistor

The effect of the antihunt resistor is shown in Figure 7. This resistance allows an additional wear of about 0.0015 inch without any damping transformer and about 0.002 inch with the present Westinghouse damping transformer. Although this antihunt resistor has a damping effect, its full benefit will not always be obtained, because part of the additional wear may be lost in the final adjustment and the regulator still satisfy all regulation and stability requirements.

From the above it can be seen that, if any electrical damping is to be used on this type regulator, the total damping should be in the form of a transformer which can be inserted after final stack and core adjustments have been made.

Optimum Damping Transformer

It can be seen from the curves of stack wear versus amount of feedback necessary for stability that one damping transformer will not compensate for infinite stack wear for all combinations of regulators and generators. Allowance for infinite stack wear is not necessary to maintain stable operation for all operating conditions.

The amount of wear a regulator can allow and still operate satisfactorily as a regulator is limited by the range of its variable resistance. After the stack has worn about 0.012 inch, the regulator cannot be adjusted for 28.5 volts or less, and the operator will see that the regulator should be returned for readjustment.

With this fact in mind, if a damping transformer is designed to allow about 0.012-inch stack wear before instability occurs, the only possibility of unstable operation is the failure of an operator to replace a regulator which obviously should be replaced. A regulator set for 28.5 volts on a 28-volt system still may

share load because of its equalizing coil, but the operator can see that it needs replacing from its no-load voltage.

To obtain the correct value of damping transformer, curves similar to the ones shown in Figures 5, 6, and 7 are necessary for each combination of generator and regulator. From these curves it can be seen that an M/R_b of about 0.0003 second would allow a maximum stack wear of 0.013 inch or greater with all combinations shown in these figures. If the regulators of manufacturer *B* without antihunt resistor, Figure 7, were omitted from this analysis (none of this type is in use) an M/R_b of 0.00022 second would allow a maximum stack wear of 0.0245 inch or greater with the other combinations.

A well-designed transformer with the foregoing amounts of damping could be made weighing five ounces or less. Present carbon-pile regulators are 2.5 pounds.

Rate of Response

Damping transformers reduce overshoot but do not materially reduce the speed of response.

Parallel Operation

In laboratory tests covered in a previous report to the Army Air Forces it was shown that, if one regulator is poorly adjusted and does not have a damping transformer, this regulator will affect the whole system and cause instability. Damping transformers on the other regulators in the system have little effect upon the poorly adjusted regulator. Therefore, for stable system operation, each individual regulator must have a damping transformer, and, if each regulator is stable in itself, the system will be stable.

Appendix I. Symbols

Generator:

R_f = resistance of shunt field

R_s = control or stack resistance in series with shunt field

r_f = total resistance of shunt field circuit (R_f+R_s)

R_a = resistance of armature, interpole, and compensating windings

L_f = self-inductance of shunt field

L_a = self-inductance of armature, interpole, and compensating windings

M = mutual inductance between shunt field and armature circuit windings, including mutual inductance of any demagnetizing or magnetizing armature, interpole, or compensating turns

T_f = $(=L_f/r_f)$ time constant of shunt field circuit

e_a = generated armature voltage

Kk_f = volts generated in the armature per ampere in the shunt field. Determined from the no-load saturation curve at maximum rated generator revolutions per minute, Kk_f is the slope of a line tangent to the saturation curve at the operating voltage

e_o = fictitious residual voltage determined by intersection of straight line assumed for Kk_f with voltage axis at zero field current; e_o includes brush drop

Kk_a = volts generated in the armature per ampere in the armature. Kk_a includes any cumulative or differential effect of brush shift or interpole and compensating windings

Load:

R_l = resistance of load

R_b = internal resistance of battery

E_b = open-circuit battery voltage

Regulator:

R_c = resistance of regulator coil

L_c = inductance of regulator coil

T_c = $(=L_c/R_c)$ time constant of regulator coil

R_m = mechanical damping of regulator in dyne centimeters per second

$1/C_m = S$, spring constant of regulator in dynes per centimeter. This includes the combination of both spring and carbon stack and is assumed to be a constant for small deviations from a given position

L_m = mass of moving portion of regulator in grams. (Value taken equal to weight of armature plus one third of carbon stack)

$t_d = M/R_b$ feed-back ratio of transformer which has the dimensions of a time constant (=transformer mutual inductance/primary resistance)

A = amplification factor of regulator. (The total amplification of the system can be expressed as AR_c which is in the order of 200 for this system)

Appendix II. Operational Equations for Generator and Load Circuits

Figure 4 shows the arrangement of the system analyzed to determine the effect of generator characteristics on the oscillatory instability condition which had been observed in service. From preliminary tests and field reports it was observed that instability occurred in a system composed of a single generator and resistance load just as readily as in more complicated systems. For this reason it was not considered necessary to analyze the more general (and more complicated) system with inductive or overhauling loads and more than one generator. Lead resistance between the generator and battery was ignored for the sake of simplicity.

The operational equations for the voltage in the different circuits are as follows:

Load circuits

$$e = E_b + i_b R_b \tag{1}$$

$$e = i_b R_l \tag{2}$$

Generator shunt field circuit

$$e = (R_s + R_f + L_f p) i_f + M p i_a \tag{3}$$

Generator armature circuit

$$e = e_a - (R_a + L_a p) i_a - M p i_f \tag{4}$$

Other relations

$$i_a = i_f + i_l \tag{5}$$

$$i_l = i_b + i_b \tag{6}$$

$$e_a = e_o + K(k_f i_f + k_a i_a) \tag{7}$$

$$r_f = R_s + R_f \tag{8}$$

If the generator is assumed to be operating at low flux density (on the straight-line portion of the saturation curve), the equation for the generated voltage is

$$e_a = e_o + K\phi \tag{9}$$

where

ϕ = flux per pole (megalines)

K = total generated armature volts per megaline of flux per pole

The flux, ϕ, is a function of both the shunt field current and the armature current.

$$\phi = k_f i_f + k_a i_a \text{ (megalines)} \tag{10}$$

k_f = megalines per pole per shunt field ampere

k_a = megalines per pole per ampere in the armature circuit

If the foregoing simultaneous equations are solved for the relationship between i_l and t, the following well-known operational equation is obtained:

$$(p^2 + \alpha p + \beta) i_l = C \text{ (amperes per second}^2\text{)} \tag{11}$$

where

$$\alpha = \frac{(R_s+R_b)[(L_f+M)(Kk_a-R_a) - r_f L_a - (Kk_f+Kk_a-R_a)M] - R_b R_s(2M+L_a+L_f)}{(R_s+R_b)(M^2-L_f L_a)} \tag{12}$$

$$\beta = \frac{(R_s+R_b)(Kk_a-R_a)r_f + R_b R_s(Kk_f+Kk_a-r_f-R_a)}{(R_s+R_b)(M^2-L_f L_a)} \tag{13}$$

and

$$C = \frac{-e\dot{b}(R_s+R_b)r_f - E_b R_s(Kk_f+Kk_a-r_f-R_a)}{(R_s+R_b)(M^2-L_f L_a)} \tag{14}$$

Equation 11 is a second-order linear operational equation whose solution is

$$i_l = \epsilon^{-\alpha/2\,t}[c_1 \epsilon^{\gamma t} + c_2 \epsilon^{-\gamma t}] + i_o \tag{15}$$

where

$$\gamma = \sqrt{\alpha^2/4 - \beta} \tag{16}$$

and

$$i_o = C/\beta$$

The integration constants c_1 and c_2 can be determined as follows from the boundary conditions of switch S having been opened previously and then closed at $t=0$:

$$c_1 + c_2 + i_{ss} = i_o \tag{17}$$

where

$$i_o = \frac{C}{\beta},\ R_s = \infty \text{ initial condition} \tag{18}$$

Capacitors for High-Frequency Induction-Heating Circuits

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Synopsis: Increased military production has accelerated the application of high-frequency heating where accurate control of temperature for short intervals is fundamentally important. The heating of metals by induction has been widely applied. The present paper describes the development of a new type of dielectric liquid called Lectronol. Capacitors containing this liquid are particularly well adapted for use in the tank circuit of electronic heaters used in induction heating. The capacitor is water-cooled and is housed in a hermetically sealed completely filled nonmagnetic container so constructed as to provide sufficient flexibility to take care of the liquid expansion due to thermal changes. The capacitor is noteworthy because of the absence of cellulose sheet insulation, satisfactory operation being entirely dependent on the superior insulating properties of the Lectronol. Capacitors containing this liquid are characterized by low dielectric loss and high dielectric strength over the frequency range utilized in power oscillators. The capacity per unit volume is approximately twice that obtained with mineral oil. The electrical characteristics of the capacitor are stable under severe conditions of use.

Paper 45-157, recommended by the AIEE subcommittee on induction and dielectric heating for publication in AIEE TRANSACTIONS. Manuscript submitted April 12, 1945; made available for printing August 4, 1945.

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The authors acknowledge the assistance given them by their associates, J. F. Byrne and G. L. Viles.

The Need for a New Capacitor

HIGH-FREQUENCY ELECTRIC power has been applied to practical industrial uses for more than 20 years. The use of high-frequency generating equipment has increased steadily during that time. Not only has such equipment been familiar to many in the communication, radio, medical, and scientific-investigation fields, but in recent years it has come to be recognized as an economic industrial machine. Particularly since the start of industrial production for military use, there has been a tremendous increase in the application of powerful high-frequency generators for concentrated heating applications. The use of high-frequency currents and voltage industrially is largely for heating where speed in attaining a localized temperature for a very short interval is fundamentally important. The heating of metals by induction and heating of nonconductive materials by dielectric absorption has been widely described in recent technical literature.[1-8]

The generation of high-frequency current, whether by rotating generators, by spark gaps, or by electronic-tube oscillators, involves tuned circuits of inductance and capacitance. Since large amounts of heat energy are most readily transferred from the power source to the part heated by the use of high voltage, high current, or both combined, we must deal with coils and capacitors as well as other components of the oscillating circuit which will stand the high-voltage stresses and carry large currents. Such a circuit is commonly referred to as a "tank" circuit because of its energy-storage properties.

Capacitors for tuning such circuits are a fundamental part of the high-frequency generating set, in fact, representing up to one third of the cost of a complete equipment in some representative designs in use. In the past, capacitors used in tank circuits operating at frequencies above 15,000 cycles have been mostly mica-di-

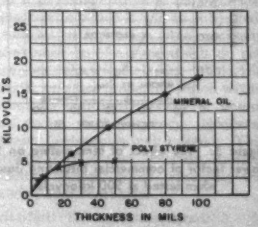

Figure 1. The dielectric-strength–thickness relation for mineral insulating oil and polystyrene films

Test temperature—25 degrees centigrade
Test frequency—500 kilocycles

$$i_{22} = \frac{C}{\beta},\ R_3 = R_2 \text{ final condition} \tag{19}$$

$$c_1 = \frac{(i_0 - i_{22})(\gamma + \alpha/2)}{2\gamma} \tag{20}$$

$$c_2 = \frac{(i_0 - i_{22})(\gamma - \alpha/2)}{2\gamma} \tag{21}$$

Appendix III. Application of Damping Transformer

The present system is idealized in Figure 8.[2] The regulator is represented by two time constants, one electrical and one mechanical which is shown by an electrical equivalent. The circuit equations for voltage changes can be written as follows:

$$e_c = (R_c + L_c p) i_c = (1 + T_c p) i_c R_c \tag{22}$$

$$R_s i_c = e_m = (R_m + 1/C_m p + L_m p) i_m \tag{23}$$

This circuit represents the mechanical part of the regulator, where the resistance is dependent upon the spring position for any one condition or, in electrical terms, the voltage output of the regulator is equal to the voltage across the condenser times the amplification of the regulator. In this analysis the amplification of the regulator is represented by a separate amplifier.

$$i_m / C_m p = e_f = (r_f + L_f p) i_f = (1 + T_f p) i_f r_f \tag{24}$$

$$i_f r_f = e_a \tag{25}$$

$$e_c = -A[e_a + t_d p(e_f - i_f R_s)] \tag{26}$$

(The negative sign is used because corrections must be opposite to deviations.)

From equations 22, 23, and 24

$$e_c = (1 + T_c p)(1/C_m + R_m p + L_m p^2)(1 + T_f p) C_m e_a \tag{27}$$

From equations 24 and 25

$$e_f = (1 + T_f p) e_a \tag{28}$$

Substituting 25 and 28 into 26 gives

$$e_c = A[1 + t_d p(1 - R_s / r_f + T_f p)] e_a \tag{29}$$

Combining equations 27 and 29 yields

$$e_a = \frac{-A e_a / C_m [1 + t_d p (R_f / r_f + T_f p)]}{(1 + T_c p)(1 + T_f p)(1/C_m + R_m p + L_m p^2)} \tag{30}$$

Upon using the constants for any particular regulator and generator combination in equation 30, a value of t_d can be obtained to give critical damping. The value necessary for critical damping can be obtained by the use of Routh's criterion without the labor of solving a fourth-order equation.

For a fourth-order equation, such as

$$ap^4 + bp^3 + cp^2 + dp + e = 0$$

the necessary condition for critical damping is that

$$bcd \geq b^2 e + d^2 a$$

where critical damping is defined that the system will be stable and nonoscillatory in the steady state.

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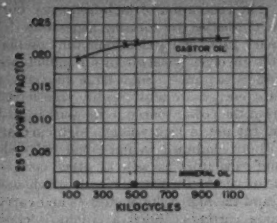

Figure 2. The comparative power-factor characteristics of mineral insulating oil and castor oil

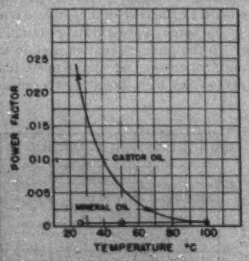

Figure 3. The effect of temperature on the power factor of commercial insulating liquids when tested at 500 kilocycles

electric types. However, the tremendous requirements for mica capacitors by the military services for communication and radar applications, along with difficulty in importing the higher grades of mica, was expected to restrict its use to those applications for which another dielectric could not be readily used. Fortunately other dielectric materials have been found possessing both better operating characteristics and economic advantages for use in induction-heating tank circuits.

What Are the Requirements of a Suitable Capacitor?

Basically, the characteristics required of capacitors for use in industrial high-frequency heaters are not widely different from those required for the familiar use in broadcast transmitters. However, the following requirements should be noted:

1. The current and voltage rating must be high to allow handling more energy. Thus it becomes desirable and economical to build higher kilovolt-ampere (kilovolts × amperes) ratings into single units to avoid a multiplicity of series and parallel connections of smaller ratings.

2. Dissipation of capacitor losses with the continuous operation necessary to meet high-production requirements in industrial plants requires adequate consideration. Although capacitor losses may be very small as compared to the total losses in a complete heater equipment, the effective dissipation of these losses with low-temperature rise is essential. Since cooling water is necessary for quenching of the heated parts, for load coils, spark gaps, vacuum tubes, or other circuit components, water-cooled capacitors are also practical. Forced-air cooling is a practical solution for the lower range of kilowatt ratings where water-cooling is undesirable.

3. Variation in operating frequency is not so critical as for radio transmitters. Therefore, the allowable variation of capacitance with temperature is not so critical in capacitors for induction heaters. This makes it possible to use a number of different dielectric materials.

4. Industrial usage requires much longer periods of operation without shutdown for maintenance or repair than has been accepted as satisfactory for earlier high-frequency radio and laboratory equipment. Reliability is, therefore, an important consideration.

5. The physical size, mounting features, means for both electric and water connections to other circuit components, and accessibility must be suitable for industrial use.

Since electronic heaters use circuits developed first for radio transmitters, the natural course was to use the same circuit components. However, as new development will permit, circuit components more adapted for industrial heating are to be desired. For example, most manufacturers recognize that economics dictates a policy of building equipment for industrial use having operating features and factors of safety which allow operation for very long periods without maintenance or inspection by technical personnel. Such has not often been true with radio equipment or laboratory equipment where constant technical supervision and frequent replacement of parts have been the practice.

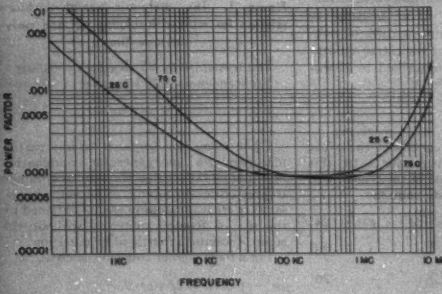

Figure 4. Power-factor versus frequency characteristics for Lectronol measured on standard concentric test cell with low-voltage oscillator

The Capacitor Dielectric Material

A rather exhaustive search of the entire field of dielectric materials suitable for high-frequency operation has been made.

Liquid dielectrics have been traditionally accepted as adaptable for high-voltage use only when used in conjunction with a solid insulation. In capacitors and cables, the solid used has invariably been paper sheets or tapes. These alone have not been satisfactory for high-voltage use because of their low-dielectric-strength value. When carefully dried and impregnated with a liquid dielectric, however, the replacement of the air normally present in the fibrous structure of the cellulose sheet by the liquid dielectric has produced a combination which has proved to be highly efficient as a dielectric for high-voltage use. In the low-frequency-capacitor application, a noninflammable synthetic liquid is particularly well adapted because of its high dielectric constant.

With the advent of the power oscillator, however, the traditional interdependency

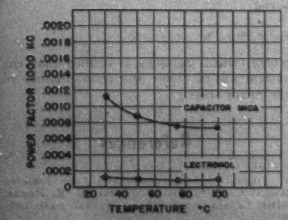

Figure 5. Comparing the temperature effect on the power factor of capacitor mica and Lectronol tested at 1,000 kilocycles

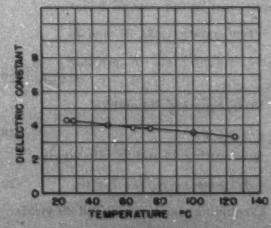

Figure 6. The dielectric-constant–temperature relation for Lectronol in the range of 100–1,000 kilocycles

of the liquid and solid insulation for high-voltage use has been subjected to critical review. The presence of the cellulose sheet insulation in capacitors operating at high voltage in the range of frequencies above 100 kilocycles has not been found to be entirely practicable. The result has been the development of a capacitor which is noteworthy because of the entire absence of cellulose sheet insulation between the electrode plates. The satisfactory operation of the capacitor is entirely dependent on the insulating liquid used. Such capacitors have been designated as "liquid-filled high-frequency parallel-plate capacitors" or more simple "class *HFP* capacitors."

The Effect of Frequency on the Dielectric Strength

Montsinger[1] has suggested that the dielectric strength of solid insulation varies with frequency and the duration of voltage application in accordance with the relation:

$$E = 1.225 + \frac{0.525}{\sqrt{T}} \times f^{-0.137}$$

where

E = dielectric strength (volts)
T = duration of voltage application (seconds)
f = frequency of test voltage (cycles per second)

Although the effect of frequency on the breakdown of solid insulation is dependent to some extent on the thickness of insulation tested, the relationship suggested by Montsinger for frequencies up to 90 kilocycles has been found to be approximately true at frequencies in the range of 100 to 1,000 kilocycles. Thus, Montsinger's relation would predict that the dielectric strength of solid insulation at 500 kilocycles would equal 30 per cent of the corresponding 60-cycle value. By actual test using dielectric pads made up of styrene films, a material of good dielectric properties at both low and high frequencies, the dielectric strength at 500 kilocycles averages 21 per cent of the 60-cycle breakdown value.

In contrast with this severe loss in dielectric strength which is exhibited by solid insulation, liquid dielectrics show marked stability. When tested at 60-cycle voltages the dielectric strength of insulating liquids in good condition averages about 30 kv, using one-inch-diameter square-edge brass electrodes, in accordance with the procedures prescribed by the American Society for Testing Materials.[2] The dielectric strength tested under the same conditions at a frequency of 500 kilocycles average about 60 per cent of the 60-cycle value. The greater dielectric-stability characteristic of insulating liquids when tested at the higher frequencies renders this type of dielectric well suited for application in high-frequency high-voltage capacitors. This is illustrated in Figure 1, which compares the dielectric strength of polystyrene and mineral oil tested at 500 kilocycles 25 degrees centigrade. It is only for the lower dielectric thickness that the solid dielectrics are possessed of dielectric strengths comparable to the liquids. It is in this manner that they have heretofore been widely used. For high-voltage use at high frequency, the liquid dielectrics have marked superiority.

Table I

Voltage	Microfarad	Microhenrys	Megacycles Resonant Frequency
2,000	0.034	0.075	3.5
2,000	0.025	0.085	3.0
6,000	0.010	0.12	4.5
6,000	0.009	0.10	5.3
9,000	0.0056	0.13	5.8
9,000	0.0029	0.12	9.0

Commercial Dielectric Liquids

Mineral transformer oil and castor oil heretofore have been considered to possess characteristics suitable for use under high-frequency voltage. In the range from 100 to 1,000 kilocycles, mineral transformer oil has low electrical loss. As illustrated in Figure 2, the power factor is less than 0.0005 at 30 degrees centigrade. Castor oil, however, has excessively high losses at room temperature. A capacitor using castor oil as a dielectric therefore would be expected to operate at temperatures well above room temperature. As illustrated in Figure 3, an increase in temperature results in a continuously decreasing electrical loss. At 100 degrees centigrade, the electrical losses in castor oil are reduced to values equally as low as those characteristic of mineral oil.

In high-frequency-capacitor use, neither of these insulating liquids is satisfactory. Mineral transformer oil, although possessing excellent high-frequency loss values, has a dielectric constant of such low value (2.18) that capacitors using this liquid possess large physical volume per microfarad. Castor oil possesses a suitably high dielectric constant (4.2 at 30 degrees centigrade). Its high electrical losses, however, coupled with its recognized chemical instability at elevated temperature, greatly restrict its application in high-frequency electric capacitors.

Electrical and Chemical Requirements

A liquid dielectric suitable for use in high-frequency plate capacitors must meet exacting electrical and chemical requirements. It must possess low electrical losses over the whole range of possible operating temperatures and frequencies. It must possess high dielectric strength. It must be chemically stable under high-voltage stress at the electrical frequencies to which it will be subjected. If subject to oxidation, the products formed must be of a type which do not affect its electrical losses, dielectric strength, or other properties which would prevent its continued successful operation under high-frequency electrical stresses. Lectronol is such a liquid. This synthetic oil is a thin, colorless, mobile, synthetic, organic liquid possessing the following characteristics:

Flash point—180 degrees centigrade
Reaction—Neutral
Pour point—−8 degrees centigrade
Dielectric constant (25 degrees centigrade)—4.4
Dielectric strength (25 degrees centigrade)—40 kv (average for 0.1-inch gap)

Power Factor or Losses

Over the frequency range utilized in power oscillators the synthetic oil described is characterized by low dielectric loss, as shown in Figure 4. As illustrated in Figure 5, the losses are even lower than those obtained with mica over the tem-

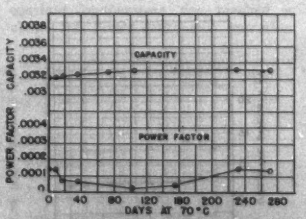

Figure 7. Illustrating the electrical stability of high-frequency parallel-plate capacitors filled with Lectronol heated at 70 degrees centigrade in contact with air

Test frequency—500 kilocycles
Temperature of electrical measurement—25 degrees centigrade

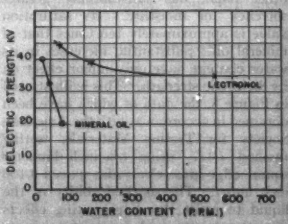

Figure 8. The dielectric strength of Lectronol is maintained at a high value even in the presence of moisture of sufficient amount to produce a marked drop in the dielectric strength of mineral oil

Test temperature—25 degrees centigrade
Test frequency—60 cycles
Test gap—100 mils

perature range from 30 to 100 degrees centigrade.

Most liquids characterized by low dielectric loss at high frequency are also characterized by a low dielectric constant. Lectronol is an exception. Although having a loss even lower than that of mica, its dielectric constant is approximately twice that of mineral oil. In Figure 6 is illustrated the dielectric constant as affected by temperature over the range from 25 to 125 degrees centigrade. The dielectric constant falls in a linear relation to the increase in temperature.

A liquid to be satisfactory for capacitor use must not only possess a suitably low dielectric loss but also be able to maintain this favorable characteristic under the most adverse operating conditions. Parallel-plate capacitors having Lectronol as the sole high-frequency dielectric show substantially no electrical deterioration even when heated for 200 days at 70 degrees centigrade (Figure 7).

Repeated studies with Lectronol substantiate its remarkable suitability for use in high-frequency capacitors. Those factors which normally would be expected to result in increased power factor have been found to have but little effect. Oxidation produces neither sludge nor dielectric deterioration. Neither power factor nor dielectric strength are affected measurably by arcing a hundred or more times when the current in the arc is of low value and not many cycles duration. Accidental arcing between capacitor plates through the liquid does not cause measurable deterioration, if the arc currents are limited to low values of a few amperes which avoids melting of the plates.

Dielectric Strength

Lectronol is characterized by a high and stable dielectric strength. Most insulating liquids, such as mineral oil, show a rapid drop in dielectric strength with increasing water content. Such liquids have but little capacity for holding water in solution. This insulating liquid, on the other hand, has substantially greater solvency for moisture. Its saturation value is approximately ten times that of mineral oil. Substantial increases in its water content have only minor effect on its dielectric strength. This is illustrated in Figure 8, the data of which have been obtained in accordance with the American Society for Testing Materials, testing method *D*117, using one-inch-diameter square-edge brass electrodes spaced 0.100 inch apart. The marked ability of the liquid to resist the deteriorating effects of contaminants, such as moisture, is reflected in its excellent dielectric strength on high-frequency voltage under conditions of practical use.

In Figure 9 are illustrated the comparative dielectric-strength values of dry liquid-filled class-*HFP* capacitors, plotted as a function of the gap distance under 550-kilocycle voltage. Even under the condition of low water content, most favorably adapted to produce the highest dielectric-strength values for mineral oil, it shows no superiority to the synthetic insulating liquid under high-frequency voltage. The excellent dielectric strength of the latter is not materially affected by temperature increase from 25 to 100 degrees centigrade (Figure 10).

Capacitor Construction

After the selection of the liquid with suitable characteristics, the plate assembly, insulators, supports, and terminal bushings are next important. The two sets of parallel plates must be spaced accurately and permanently, for which heavy-gauge aluminum stock is most desirable. The two plate assemblies must be rigidly supported and yet allow for thermal expansion, which is accomplished with Mycalex plates. This insulating material has very good high-frequency voltage strength as well as low loss under high-frequency stress and also high mechanical strength. More than ample voltage-creepage surfaces are obtained readily with the large sheet used.

Very effective water cooling of the assembly is obtained by connecting the cooling coil to the grounded set of plates, thus giving direct heat flow from the plates through the connectors into the tubing and into the water. Also the water tubing serves as a current conductor, making possible small-size high-current connections going directly to the load transformer or tank coil. Current-carrying connections between series or parallel connected units may be combined with cooling water tubing connections.

The container is nonmagnetic of double-lock seam construction, providing sufficient flexibility in side walls to take care of liquid expansion due to thermal changes. The case is completely filled with liquid and hermetically sealed. Removable footed-type mounting brackets are provided for supporting the capacitor in any desired position, protecting the ends from damage and yet not interfering with flexibility of the capacitor sides.

Terminal bushings require particular design consideration to obtain sufficiently low-voltage stress distribution to avoid dielectric heating in the insulating material and yet have high current-carrying capacity. When a hollow shell type of ceramic bushing is used and the interior is filled with the low-loss, high-strength liquid, the dielectric loss in the bushing assembly is held to a minimum, and liquid cooling about the current-carrying parts is effective in dissipating losses. Two or more such bushings, connected in parallel to split the current and having water-cooling tube connections at the top, allow high-current operation of a single capacitor. For voltage ratings of six kilovolts and above, corona shields added at the base of the bushing are an advantage, making it possible to use a smaller bushing and less creepage surface and at the same time providing a definite flashover voltage value at a point away from the ceramic surface.

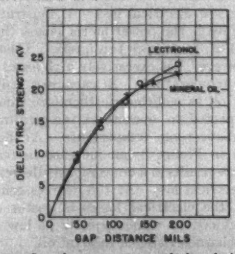

Figure 9. A comparison of the dielectric-strength characteristics of high-frequency parallel-plate capacitors filled with dry mineral oil and Lectronol measured at 25 degrees centigrade under 500-kilocycle test voltages

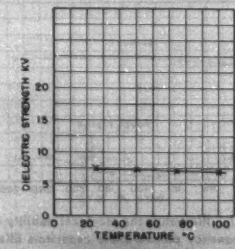

Figure 10. The effect of temperature on the dielectric strength of high-frequency parallel-plate capacitors filled with Lectronol

Test frequency—500 kilocycles
Gap distance—36 mils

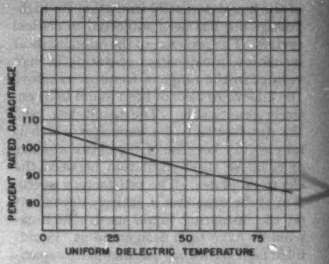

Figure 11. Variation of capacitance with temperature in degrees centigrade measured at 60 cycles

Electrical Characteristics

It is comparatively easy to maintain a close tolerance in capacitance of ± 5

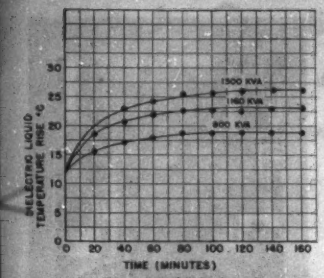

Figure 12. Typical dielectric-liquid temperature rise in degrees centigrade above outlet water temperature variation with time in operation for high-frequency parallel-plate capacitor rated 0.0056 microfarad, 500 kilocycles, and one-half-gallon-per-minute water flow

per cent in production of such capacitors, as capacitance variation between units is almost entirely a result of variation in physical dimensions.

Change in capacitance with temperature is dependent on both change in dielectric constant of liquid temperature and change in physical spacing of plates with linear metallic expansion. Capacitance variation with temperature is between one fourth and one third of 1 per cent per degree centigrade as shown by Figure 11. This change in capacity is recognized as being too great for use where the frequency of the tank circuit must be held within narrow limits, such as for radiobroadcasting. However, a slight change in frequency of three to four per cent which is typical of changes from no-load to full-load operating temperature is not objectionable for induction heating. The use of cooling water aids appreciably in holding a constant operating temperature in capacitors, as the full-load continuous temperature rise is held to a reasonably low value.

The internal inductance of such capacitors is low with only a small variation due to change in physical dimensions such as height of terminal bushings above the case. Since internal inductance varies only between 0.075 and 0.13 microhenrys, the resonant frequency varies with the microfarad rating as shown by Table I.

Though individual capacitors with minimum length of bus connections are suitable for operation at several megacycles, particular consideration must be given to keeping the length of the tank circuit and loop area of the circuit connections at a minimum, if the higher-frequency range of the capacitors is to be utilized.

An outstanding characteristic is the low loss of these capacitors at high frequency. Losses are a combination of I^2R or metallic-conductor loss and the dielectric loss in the liquid. Metallic losses are low, because design features include parallel-current paths, good electric conductors, and well-made joints between conductors. In fact in the practical application losses in the tank coil and the two capacitor terminals are a much larger factor than the internal losses of the capacitor. For example, a capacitor rated 0.0056 microfarad operating at 540 kilocycles, 9,000 volts rms, and 171 amperes, on continuous operation will show 3.3 degrees rise in cooling water with a flow rate of one-half gallon per minute. Using the constant of 31.6 watts per pound of water per minute per degree centigrade, we calculate a total loss of 448 watts.

Thus, the calculated power factor with full-load operation at 1,539 kva is 0.00029. With reference to Figure 5, the liquid dielectric power factor is 0.0001, leaving a power factor of 0.00019 assignable to I^2R or metallic losses.

Some designers prefer the use of Q factor for comparison of circuit component losses. As the Q factor of a capacitor is equal to the reciprocal of the per cent power factor times 100, we get a factor of approximately 3,450 for this rating and operating load.

The use of water cooling tends to stabilize operating temperatures with constant temperature rise reached in about $1\frac{1}{2}$ hours continuous operation. Typical temperature-rise curves are shown in Figure 12. The outlet water temperature controls the operating temperature of the capacitor. In order that the temperature of the dielectric liquid does not exceed 68 degree centigrade, the outlet water temperature is limited to 35 degrees centigrade at 1,500 kva and above. With a limit on operating temperature of liquid, it is reasonable that outlet temperature may be higher when kilovolt-ampere loading is lower, as shown by Figure 13. For economy in use of cooling water, several capacitors may be connected in series for water flow, depending on the pressure available. Figure 14 shows the pressure drop per capacitor for a range of different water-flow rates. The temperature rise in the cooling water is low and dependent on the operating kilovolt-amperes as shown by Figure 15.

Basis of Rating

The voltage rating is fixed by two factors:

1. The maximum peak transient voltage which the capacitor is expected to withstand.
2. The continuous rms operating voltage which contributes to the temperature rise or heating load on a capacitor.

Consistent with dielectric strength of the liquid and plate spacing, all capacitors are designed for operation with transient voltage peaks not to exceed 200 per cent of the rms high-frequency rating.

The usual practice of listing test-voltage ratings on mica capacitors in place of maximum continuous rms rating has not proved to be satisfactory for industrial application. Having only the ultimate short-time voltage strength listed as a rating makes it necessary for each designer of equipment in which mica capacitors are used to decide for himself the factor of safety to be allowed on operating voltage as against test voltage. In too many cases the pressure of space requirements and economics, along with inex-

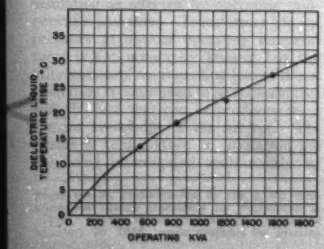

Figure 13. Typical dielectric-liquid temperature rise in degrees centigrade above outlet water-temperature variation with operating kilovolt-amperes for capacitor rated 0.0056 microfarad, nine kilovolts, 540 kilocycles with one-half-gallon-per-minute water flow

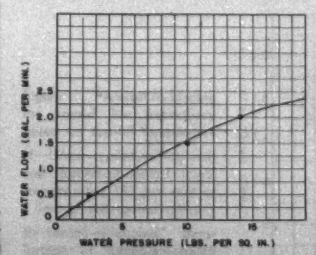

Figure 14. Water-flow variation with pressure applied to cooling coil of high-frequency parallel-plate capacitors

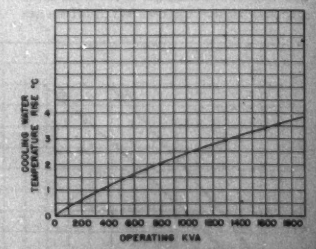

Figure 15. Variation in cooling-water temperature rise in degrees centigrade with operating kilovolt-amperes for high-frequency parallel-plate capacitor rated 0.0056 microfarad, nine kilovolts, 540 kilocycles

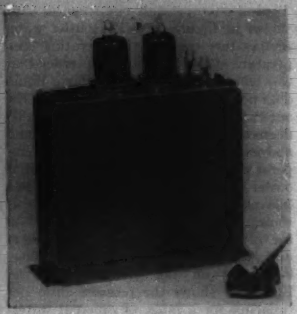

Figure 16. General Electric high-frequency parallel-plate capacitor unit for electronic-heater resonant-circuit applications

High-frequency, parallel-plate, water-cooled, rated 0.0056 microfarad, 9,000 volts, 171 amperes, at 540 kilocycles

perience on life statistics if at all available, all lead to the result that mica capacitors are used with insufficient factor of safety for continuous operation.

It is essential that adequate consideration be given to the effective dissipation of losses for continuous operation of all capacitors and that operation is in accordance with predetermined ratings under which the capacitor is designed to operate. For a safe economical industrial installation, a capacitor designer must establish the operating rating.

For class-*HFP* capacitors both voltage and current ratings are based on a frequency of 540 kilocycles which has been selected as being in the most popular range for electronic induction-heater operation. As the capacitor is rated for a maximum voltage at 540 kilocycles, the current rating at lower frequencies must be reduced in direct proportion to the frequency change, while the voltage rating remains unchanged. For frequencies above 540 kilocycles, the current rating can be increased to limits allowed by operating temperatures of the dielectric liquid and terminal conductors. Water cooling of terminal conductors has been found practical because of much higher current rating allowed. For example, a typical pair of terminals as shown by Figure 16 will carry 95 amperes at 540 kilocycles with 45 degrees rise when connected with conductors having natural air cooling but will carry 171 amperes when connected to water-cooled tubing with approximately the same rise.

Conclusions

1. A much improved and more economical high-voltage high-current tank circuit capacitor has been developed for induction-heating and dielectric-heating oscillators.

2. A new high-dielectric-strength liquid with high dielectric constant and very low loss over a wide frequency range has been applied in a practical fixed-plate capacitor design. Having the container, including terminal bushings, completely filled with liquid and hermetically sealed insures that the capacitor will keep its original electrical characteristics.

3. Installation of capacitors with larger sizes required for electronic heaters has been simplified. Maintenance cost has been reduced because of larger factor of safety from overheating on continuous operation in high ambient temperatures.

4. Large amounts of mica previously used for capacitors in electronic heating oscillators have been saved for military radio and radar applications requiring capacitors with minimum change in capacitance with temperature and requiring physical dimensions interchangeable with standard mica capacitor sizes previously available.

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Figure 17. Rear view of electronic heater, 15 kw, type F-15, model 4F15E1, without rear door

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Guides for Operation of Transformers, Regulators, and Reactors

AIEE TRANSFORMER SUBCOMMITTEE

Guide for Loading Oil-Immersed Distribution and Power Transformers

Scope

THIS guide covers general recommendations for loading all types of oil-immersed transformers with class-*A* insulation except water-cooled transformers built before 1929, self-cooled transformers rated at 200 kva or less, and transformers having a rated full-load current less than ten amperes. They include transformers immersed in synthetic or noninflammable liquids.

The manufacturer should be asked for recommendations relating to water-cooled transformers built before 1929 and for more specific recommendations for large and important transformers if required.

Caution

It must be recognized that loads above rating should not be applied without a thorough study of the various limitations involved. Among these limitations are oil expansion, pressure in sealed-type units, bushings, leads, soldered connections, tap changers, and the thermal capability of associated equipment such as cables, reactors, circuit breakers, disconnecting switches and current transformers. These may constitute the practical limit in load-carrying ability.

Before loading apparatus above rating to the full extent covered in these guides, it is recommended that load capabilities be checked with the manufacturer.

General

Recommendations in this guide are based on life expectancy of transformer insulation as affected by operating temperature and time. Transformer life expectancy at various operating temperatures is not accurately known, but the information given regarding loss of life of insulation is considered to be conservative and the best that can be produced from present knowledge of the subject. The effects of temperature on insulation life are being investigated continuously by the transformer subcommittee, and new findings may affect future revision of the guides. The word "conservative" is used in the sense that the expected loss of insulation life for a single recommended overload will not be greater than the amount stated.

The rated kilovolt-ampere output of a transformer is that load which it can deliver continuously at rated secondary voltage without exceeding a given temperature rise measured under prescribed test conditions. The temperature rise on which the rating is based takes into consideration the experience of the industry regarding

1. Insulation life as affected by operating temperature.
2. The ambient temperatures assumed to exist throughout the life of the transformer.

The actual output which a transformer can deliver at any time in service without undue deterioration of the insulation may be more or less than the rated output, depending upon the ambient temperature and other attendant operating conditions.

Practically all of the data in reference to the aging of insulation at different temperatures has been obtained in laboratory tests in which the decrease in mechanical strength has been measured. The relation between the life expectancy of insulation as indicated by laboratory tests and the actual life of a transformer is largely theoretical, so that loading based on such information must be tempered by sound judgment based on experience.

As the evaluation of the cumulative effects of temperature and time in causing deterioration of transformer insulation is not thoroughly established, it is not possible to predict with any great degree of accuracy the length of life of a transformer even under constant or closely controlled conditions, much less under widely varying service conditions.

The change in rate of deterioration with change in temperature has received much study, but the actual values for different operating temperatures are not completely agreed on. An average value which has been used for a number of years is that the rate of deterioration doubles with each eight degrees centigrade that the temperature of the insulation increases. This value is not accurate for all temperatures nor for all points in the life of a transformer. It is given here to show the importance of controlling ambient temperatures in indoor installations by means of ventilation, thus controlling the insulation temperature and life.

Owing to the many variables mentioned and particularly to the many varying conditions of load and ambient to which a transformer can be subjected in service, it is not possible to give definite rules for the loading of transformers. It is only possible to give suggested loadings under specified conditions and look to the user to make the best use of this information for his particular problem.

Ambient Temperatures and Loading for Normal Life Expectancy

The basic loading condition of a transformer for normal life expectancy is continuous loading at rated kilovolt-amperes and rated delivered voltage with the temperature of the cooling air at no time exceeding 40 degrees centigrade and with the average temperature of the cooling air during any 24-hour period equal to 30 degrees centigrade. For water-cooled transformers comparable temperatures are 30 and 25 degrees centigrade, the five-degree-centigrade lower average temperature of the cooling medium being to allow for possible less efficient cooling due to coils that are not clean. (It is assumed that operation under the foregoing conditions is equivalent to operation at a continuous ambient temperature of 30 degrees centigrade for cooling air and 25 degrees centigrade for cooling water.)

The hottest-spot copper temperature is the sum of the temperature of the cooling medium, the average temperature rise

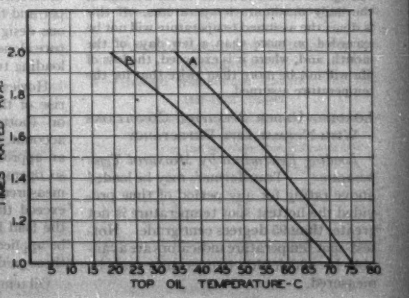

Figure 1. Permissible loading for normal life expectancy based on top-oil temperature

A—Water-cooled, self-cooled, and forced-air-cooled transformers rated 133 per cent or less of self-cooled rating

B—Forced-oil-cooled transformers or forced-air-cooled transformers rated over 133 per cent of self-cooled rating

Paper 45-130, recommended by the AIEE committee on electric machinery for publication in AIEE Transactions. Manuscript submitted February 26, 1945; made available for printing May 23, 1945.

This paper is a complete revision of American Recommended Practice—Guides for Operation of Transformers and Regulators, American Standard C57.3—1942. It will be presented to the American Standards Association sectional committee on transformers C57 for inclusion in proposed revision of transformer Standards.

of the copper and the hottest-spot allowance. For oil-immersed transformers operating continuously under the foregoing conditions with normal life expectancy this temperature has been assumed to be 95 degrees centigrade.

Other usual service conditions, as given in American Standard C57.1, section 2.000, must be complied with.

Years of experience have indicated that a transformer rated in accordance with the Standard and operated under the foregoing conditions will have a reasonably long life.

Ambient Temperatures

Ambient temperature is an important factor in determining the load capability of a transformer. Whenever the actual ambient temperature can be determined from readings taken at the time of the load being considered, such temperatures should be used.

It is often necessary to predict the load that a transformer can carry safely at some future time when the actual ambient temperature is unknown. A method of approximating the ambient temperature for the month in which the expected load is anticipated is as follows (Temperatures referred to are contained in reports prepared by the Weather Bureau of the United States Department of Commerce and are available for various sections of the country):

1. For loads with normal life expectancy:

Use the average temperature over a period of years for the month involved. Some believe that this temperature should be increased by as much as five degrees centigrade because

(a). The average temperature for a given month may be above the average temperature of the same month for a period of years.

(b). Increased aging at higher than average temperature is not offset by decreased aging at lower than average.

2. For short-time loads with moderate sacrifice of life expectancy:

Use the average of the daily maximum temperatures for the month involved averaged with similar values for the same month over a period of years.

During any one day there is an even chance that the maximum temperature will exceed this value. Some feel that five degrees centigrade should be added to the average of the daily maximum temperatures. If this is done, the assumed temperature will not be exceeded on more than a few days of the month, and, where it is exceeded, the loss of life will not be more than twice that for the temperature assumed.

Loading Under Specified Conditions With Normal Life Expectancy

Loading Determined by Measured Temperature. Transformers may be loaded above rating for any period of time provided the hottest-spot temperature is not greater than 95 degrees centigrade. Hottest-spot temperature indicators are available by which this temperature may be measured.

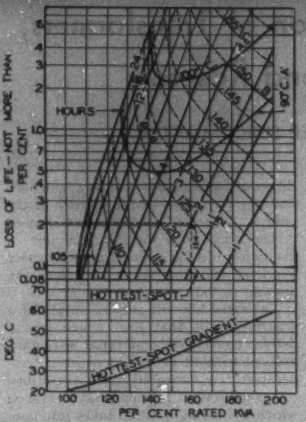

Figure 2. Short-time loading with moderate sacrifice of life expectancy, self-cooled and water-cooled transformers

Following 50 per cent or less of rated kilovolt-amperes or top-oil temperature rise of 25 degrees centigrade

Ambient temperature 30 degrees centigrade for air, 25 degrees centigrade for water

Subtract hottest-spot gradient from hottest-spot temperature to obtain top-oil temperature

A—Assumed temperature limitation for top oil (protected)

A'—Assumed temperature limitation for top oil (unprotected)

B—Assumed temperature limitation for hottest-spot copper

Time, Hours	Times Rated Kilovolt-Amperes to Use not More Than Following Life (Per Cent)			
	0.1	0.25	0.50	1.0
½	2.00	2.00	2.00	2.00
1	1.76	1.91	2.00	2.00
2	1.50	1.62	1.72	1.82
4	1.27	1.38	1.46	1.53
8	1.13	1.21	1.30	1.37
24	1.05	1.10	1.15	1.23

For explanation of degree of accuracy, see Appendix II.

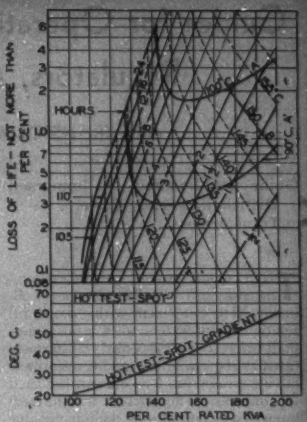

Figure 3. Short-time loading with moderate sacrifice of life expectancy, self-cooled and water-cooled transformers

Following 100 per cent of rated kilovolt-amperes or top-oil temperature rise of 45 degrees centigrade

Ambient temperature 30 degrees centigrade for air, 25 degrees centigrade for water

Subtract hottest-spot gradient from hottest-spot temperature to obtain top-oil temperature

A—Assumed temperature limitation for top oil (protected)

A'—Assumed temperature limitation for top oil (unprotected)

B—Assumed temperature limitation for hottest-spot copper

Time, Hours	Times Rated Kilovolt-Amperes to Use not More Than Following Life (Per Cent)			
	0.1	0.25	0.50	1.0
½	1.75	1.92	2.00	2.00
1	1.54	1.69	1.81	1.92
2	1.35	1.48	1.58	1.68
4	1.20	1.32	1.40	1.48
8	1.11	1.20	1.28	1.35
24	1.05	1.09	1.15	1.23

For explanation of degree of accuracy, see Appendix II.

On account of large variations in the difference between the hottest-spot copper and the top-oil temperatures of various designs under full load, oil temperature alone should not be used as a guide in loading transformers.

However, by taking the temperature rise of the hottest-spot copper over top oil (hottest-spot copper gradient) into account, oil temperatures may be used as an approximate guide in loading. When so operated for any period of time, the measured top-oil temperature should not exceed the values given in Figure 1 for the load being carried. These loads can be applied to any transformer covered by these guides as they are conservative.

Oil temperatures may be used as a more accurate guide, by using the hottest-spot copper gradient of any particular transformer for the load it is carrying at the time. If the hottest-spot copper gradient at full load is known, the gradient at other loads may be determined easily by using Figure 10 in Appendix II. The limiting oil temperature for normal life expectancy for any load, regardless of the time carried, can be determined by subtracting the hottest-spot copper gradient for that load from 95 degrees centigrade.

Loading on Basis of Test Temperature Rise. For each degree centigrade in excess of two degrees that the test temperature rise is below the standard temperature rise specified in the Standard, the transformer

load may be increased above rated kilovolt-amperes by the percentages shown in second column of Table I. Making use of this factor gives the kilovolt-amperes that the transformer can deliver with 55 degrees centigrade temperature rise. The leeway of two degrees is to provide for a negative tolerance in the measurement of temperature rise.

Some transformers are designed to have the difference between hottest-spot and average copper temperatures greater than the nominal allowance of ten degrees centigrade. This will result in a temperature rise for average copper of less than 55 degrees centigrade, but the hottest-spot copper temperature rise may be at the limiting value of 65 degrees centigrade.

Such transformers should not be loaded above rating as outlined under this heading. The manufacturer should be consulted to give information as to design hottest-spot allowances.

Loading on Basis of Ambient Temperature. For each degree centigrade that the average temperature of the cooling medium is above or below 30 degrees centigrade for air or 25 degrees centigrade for water, a transformer may be loaded for any period of time below or above its kilovolt-ampere rating as specified in Table I. Average temperature should be for periods of time not exceeding 24 hours with maximum temperatures not more than ten degrees centigrade greater than average temperatures for air and five degrees centigrade for water. On the basis used in this guide for calculating loss of life, life expectancy will be approximately the same as if it had been operated at rated kilovolt-amperes and standard ambient temperatures over that period.

The use of transformers in cooling air above 50 degrees centigrade, or below 0 degrees centigrade, or with cooling water above 35 degrees centigrade is not covered by Table I and should be taken up with the manufacturer.

Loading on Basis of Load Factor. When the load factor for a period of time not exceeding 24 hours is below 100 per cent, the maximum loading of a transformer during that period may be increased above rated kilovolt-amperes by the percentages shown in Table II for each per cent that the load factor is below 100 per cent. On the basis used in this guide for calculating loss of life, life expectancy will be approximately the same as if it had been operated at rated kilovolt-amperes during that period.

Loading on Basis of Short-Time Loads Above Rating. When short-time loads above rating occur not more than once in any 24-hour period, the maximum loading of a transformer during that period may be increased conservatively above rated kilovolt-amperes, as given in Table III. On the basis used in this guide for calculating loss of life, life expectancy will be approximately the same as if it had been operated at rated kilovolt-amperes during that period.

Effect of Various Factors Existing at One Time. When two or more of the following factors affecting loading for normal life expectancy exist at one time, the effects are cumulative and the increase in loads due to each may be added to secure the maximum suggested load (each increase must be based on rated kilovolt-amperes):

1. Loading on basis of test temperature rise.
2. Loading on basis of ambient temperature.
3. Either loading on basis of load factor or loading on basis of short-time overloads. Do not use both.

Short-Time Loading With Moderate Sacrifice of Life Expectancy

To be able to give an idea of the relative loss of life due to loads above rating under various conditions, we have assumed a conservative aging rate of insulation based on tests and operating experience. The information is not intended to furnish a basis for calculating the normal life expectancy of transformer insulation.

Transformers may be loaded above rated kilovolt-amperes following various

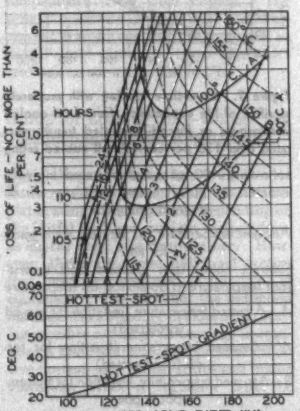

Figure 4. Short-time loading with moderate sacrifice of life expectancy, forced-air-cooled transformers rated 133 per cent or less of self-cooled rating

Following 50 per cent or less of rated kilovolt-amperes or top-oil temperature rise of 25 degrees centigrade

Ambient temperature 30 degrees centigrade for air

Subtract hottest-spot gradient from hottest-spot temperature to obtain top-oil temperature

A—Assumed temperature limitation for top oil (protected)

A'—Assumed temperature limitation for top oil (unprotected)

B—Assumed temperature limitation for hottest-spot copper

Time, Hours	Times Rated Kilovolt-Amperes to Use not More Than Following Life (Per Cent) 0.1	0.25	0.50	1.0
1/2	1.97	2.00	2.00	2.00
1	1.66	1.79	1.90	2.00
2	1.39	1.51	1.59	1.68
4	1.21	1.31	1.38	1.45
8	1.11	1.19	1.26	1.33
24	1.05	1.09	1.15	1.22

For explanation of degree of accuracy, see Appendix II.

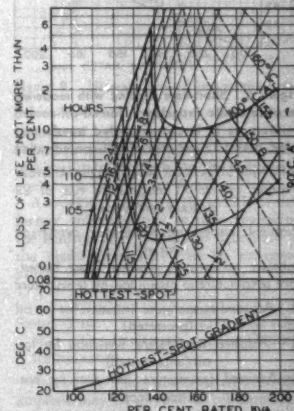

Figure 5. Short-time loading with moderate sacrifice of life expectancy, forced-air-cooled transformers rated 133 per cent or less of self-cooled rating

Following 100 per cent of rated kilovolt-amperes or top-oil temperature rise of 45 degrees centigrade

Ambient temperature 30 degrees centigrade for air.

Subtract hottest-spot gradient from hottest-spot temperature to obtain top-oil temperature

A—Assumed temperature limitation for top oil (protected)

A'—Assumed temperature limitation for top oil (unprotected)

B—Assumed temperature limitation for hottest-spot copper

Time, Hours	Times Rated Kilovolt-Amperes to Use not More Than Following Life (Per Cent) 0.1	0.25	0.50	1.0
1/2	1.67	1.82	1.94	2.00
1	1.47	1.60	1.71	1.81
2	1.29	1.41	1.50	1.58
4	1.18	1.28	1.35	1.43
8	1.10	1.18	1.26	1.33
24	1.05	1.09	1.15	1.21

For explanation of degree of accuracy, see Appendix II.

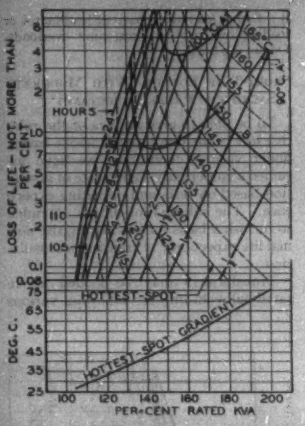

Figure 6. Short-time loading with moderate sacrifice of life expectancy, forced-oil-cooled transformers or forced-air-cooled transformers rated over 133 per cent of self-cooled rating

Following 50 per cent or less of rated kilovolt-amperes or top-oil temperature rise of 22 degrees centigrade

Ambient temperature 30 degrees centigrade for air

Subtract hottest-spot gradient from hottest-spot temperature to obtain top-oil temperature

A—Assumed temperature limitation for top oil (protected)

A'—Assumed temperature limitation for top oil (unprotected)

B—Assumed temperature limitation for hottest-spot copper

Time, Hours	Times Rated Kilovolt-Amperes to Use not More Than Following Life (Per Cent) 0.1	0.25	0.50	1.0
½	1.78	1.92	2.00	2.00
1	1.53	1.64	1.73	1.82
2	1.32	1.42	1.49	1.57
4	1.18	1.26	1.33	1.40
8	1.10	1.17	1.24	1.31
24	1.05	1.08	1.14	1.20

For explanation of degree of accuracy, see Appendix II.

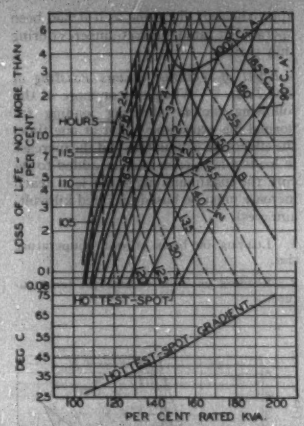

Figure 7. Short-time loading with moderate sacrifice of life expectancy, forced-oil-cooled transformers or forced-air-cooled transformers rated over 133 per cent of self-cooled rating

Following 100 per cent of rated kilovolt-amperes or top-oil temperature rise of 40 degrees centigrade

Ambient temperature 30 degrees centigrade for air

Subtract hottest-spot gradient from hottest-spot temperature to obtain top-oil temperature

A—Assumed temperature limitation for top oil (protected)

A'—Assumed temperature limitation for top oil (unprotected)

B—Assumed temperature limitation for hottest-spot copper

Time, Hours	Times Rated Kilovolt-Amperes to Use not More Than Following Life (Per Cent) 0.1	0.25	0.50	1.0
½	1.55	1.70	1.80	1.90
1	1.39	1.50	1.59	1.69
2	1.26	1.36	1.43	1.51
4	1.16	1.25	1.32	1.39
8	1.10	1.18	1.24	1.31
24	1.05	1.09	1.14	1.20

For explanation of degree of accuracy, see Appendix II.

loads by various amounts for various times, and the approximate relative loss of life may be estimated.

The load capability of transformers varies widely and is affected by the following characteristics:

1. Top-oil rise over ambient temperature.
2. Hottest-spot rise over top-oil temperature (hottest-spot copper gradient).
3. Ratio of load losses to no-load loss.
4. Time constant.*
5. Ambient temperature.

It is not possible to give a single set of loads which will apply to all transformers for a given set of operating conditions. Therefore, such values are given for a transformer having specified characteristics, and these characteristics have been selected so that allowable loads for practically all other combinations of characteristics will be at least as great as those given.

As the operating conditions under which transformers may be loaded are so extremely variable, particularly with regard to frequency of load, data are given so that the approximate relative loss of insulation life for various loads for various times may be determined. The user can then determine the allowable load for his conditions by taking into account the probable number of such loads during the life of the transformer and the approximate percentage of life which he is willing to sacrifice.

Appendix I gives a method by which the user can produce similar data for transformers having other characteristics, and the loads for a given hottest-spot temperature may be somewhat greater than those given hereafter.

In the curves and tables that follow, the following limitations have been used:

Maximum oil temperature (unprotected)* . . . . . 90 degrees centigrade†

Maximum oil temperature (protected)* . . . . . 100 degrees centigrade‡

Maximum hottest-spot copper temperature . . . . . 150 degrees centigrade

Maximum short-time loading (one-half hour or more) . . 200 per cent**

Short-Time Loads Above Rating for Transformer With Specified Characteristics

Assumed Transformer Characteristics. (See Table IV.) By the use of the data in the Table V the user may determine hottest-spot copper temperature for various loads and times following 50-per-cent load or less and 100-per-cent load and from this determine the approximate loss of life for such loading. Or he may determine loading for any selected loss of life. The user can select loadings and losses of life most suitable to his conditions. An average loss of life of one per cent per year incurred during emergency operations is considered reasonable.

Top-oil temperature, when known, is a better criterion of conditions at the start of a given load than the previous conditions of load, because the oil may not have reached its ultimate temperature for the previous load.

On each of the afore-mentioned figures ultimate top-oil temperature rise for the preceding load is given. This value may be used to determine the curve to use and as a guide in interpolation.

Hottest-spot copper temperatures versus loss of life assumed in making up figures are given in Figure 11.

Additional Short-Time Loading Available. In addition to the short-time loads outlined, the transformer may be loaded above or below kilovolt-ampere rating in accordance with directions given under "Loading for Normal Life Expectancy." (Each increase must be based on rated kilovolt-amperes.)

1. Loading on basis of test temperature rise.

*See Appendix II for explanation.

†Oil is considered to be protected, or unprotected, depending on whether the transformer is or is not equipped with conservator or inert gas above the oil.

‡At high oil temperatures precautionary measures, such as draining oil, may be necessary to prevent overflow or excessive pressures.

**Current-carrying parts, other than windings, may impose a lower limit.

2. Loading on basis of ambient temperature.

Thermal Relays

Thermal relays designed for application to individual transformers are available. They make use of hottest-spot temperature in their operation and automatically take into account ambient temperature and previous conditions of loading, since the actuating element is influenced by the hottest oil and the load current. Higher loads are permitted for short times than are permitted for long times. These relays can be designed, at the option of the user, to permit loads which will produce practically no sacrifice of life expectancy or some predetermined moderate sacrifice of such expectancy. Contacts may be wired to cause sounding an alarm, starting of fans, or disconnecting of the transformer. Application of such relays should be discussed with the manufacturer.

Supplemental Cooling of Existing Self-Cooled Transformers

The load that can be carried on existing self-cooled transformers can be increased by as much as 66 per cent by adding auxiliary cooling equipment such as fans, external forced-oil coolers, or water-spray equipment. The amount of additional loading varies widely, depending on:

(*a*). Design characteristics of the transformer.

(*b*). Type of cooling equipment.

(*c*). Permissible increase in voltage regulation.

(*d*). Limitations of associated equipment.

Table I. Loading on Basis of Ambient Temperature

Type of Cooling	Per Cent of Rated Kva: Decrease Load for Higher Temp	Per Cent of Rated Kva: Increase Load for Lower Temp
Self-cooled	1.5	1.0
Water-cooled	1.5	1.0
Forced-air-cooled	1.0	0.75
Forced-oil-cooled	1.0	0.75

No general guides can be given for such supplemental cooling, and each transformer should be considered individually.

Guide for Loading Pole-Type Constant-Current Transformers

Increased Periods of Operation of Pole-Type Constant-Current Transformers for Ambient Temperatures Lower Than Normal

Since pole-type constant-current transformers operate outdoors at night when the ambient temperature is comparatively low, it is often desirable to take advantage of the longer period of operation within the limiting temperature rise which is made possible by an ambient temperature lower than normal. The time of operation of a pole-type constant-current transformer may be increased as the average ambient temperature decreases, as shown in Table VI.

Guide for Loading Step-Voltage and Induction-Voltage Regulators

A voltage regulator has a short-time load capability greater than the nameplate rating, the magnitude depending on the initial load and ambient temperature, as in the case of a transformer. However, there are some additional factors that must be considered in this type of equipment. The fact that the induction machine has a winding in slots on a rotating member mounted in bearings necessitates a limit to the load to prevent excessive hottest-spot temperatures and undue vibration. Also, a regulator must be capable of operating or holding against the torque produced by load. In the case of a step-voltage regulator, the burning of contacts is the limiting feature.

Table II. Loading on Basis of Load Factor

Type of Cooling	Increase in Per Cent of Rated Kva	Maximum Per Cent Increase*
Self-cooled	0.5	25
Water-cooled	0.5	25
Forced-air-cooled	0.4	20
Forced-oil-cooled	0.4	20

* Corresponds to 50 per cent load factor.

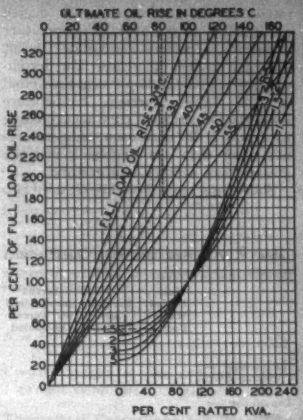

Figure 8. Ultimate top-oil temperature rise

A working group of the AIEE transformer subcommittee is now reviewing the loading of regulators to determine if the loads given here can be increased safely.

Short-Time Loads Above Rating for Oil-Immersed Self-Cooled Regulators

Short-time loads above rated kilovolt-amperes may be applied to oil-immersed self-cooled regulators with daily average cooling air at 30 degrees centigrade in accordance with the limits given in Table VII.

Loads with normal life expectancy may be carried once every 24 hours, whereas those with moderate sacrifice of life expectancy should be carried infrequently.

With cooling-air temperatures other than 30 degrees centigrade the short-time loads may be increased by one per cent of

Table III. Loading on Basis of Short-Time Loads Above Rating

Time, Hours	Times Rated Kilovolt-Amperes: Self-Cooled and Water-Cooled Transformers			Forced-Air-Cooled Transformers Rated 133 Per Cent or Less of Self-Cooled Rating			Forced-Air-Cooled Transformers Rated More than 133 Per Cent of Self-Cooled Rating and All Forced-Oil-Cooled		
*Initial Load (per cent)	90	70	50	90	70	50	90	70	50
½	1.59	1.77	1.89	1.45	1.58	1.68	1.36	1.47	1.50
1	1.40	1.54	1.60	1.31	1.38	1.50	1.24	1.31	1.34
2	1.24	1.33	1.37	1.19	1.23	1.26	1.14	1.18	1.21
4	1.12	1.17	1.19	1.11	1.13	1.15	1.09	1.10	1.10
8	1.06	1.08	1.08	1.06	1.07	1.07	1.05	1.06	1.06

*Percentages fix the load which is assumed to exist before the short-time load is applied. Use either average load for two hours previous to load above rating or average load for 24 hours (less overload period), whichever is greater.

Ambient temperature assumed for this table is 30 degrees centigrade for air and 25 degrees centigrade for water.

As the loads may be applied once every 24 hours, and as there is some evidence that the rate of insulation deterioration at about 100 degrees centigrade doubles with less than 8 degrees centigrade increase in insulation temperature the values have been based on 4 degrees centigrade rather than on 8 degrees centigrade.

rated kilovolt-amperes for each degree centigrade that the average temperature is below 30 degrees centigrade, except that no further increases are recommended beyond the 25-per-cent limit cited in the table. Average temperature should be for periods of time not exceeding 24 hours with maximum temperatures not more than ten degrees centigrade greater than average temperatures.

Short-time loads should be reduced two per cent of the continuous self-cooled rating below the recommended load for each degree centigrade that the daily average temperature of the cooling air exceeds 30 degrees centigrade.

Table IV. Assumed Transformer Characteristics

	Self-Cooled Water-Cooled	Forced-Air-Cooled*	Forced-Air-Cooled† or Forced-Oil-Cooled
Hottest-spot rise (degrees centigrade)	65	65	65
Top-oil rise (degrees centigrade)	45	45	40
Time constant at full load (hours)	3.0	2.0	1.5
Ratio of copper to iron losses	2.5 to 1	3.5 to 1	5 to 1
Ambient temperature (degrees centigrade)	30	30	30

*Forced-air-cooled rating is 133 per cent or less of self-cooled rating.

†Forced-air-cooled rating is over 133 per cent of self-cooled rating.

Table V. Reference to Figures

	Self-Cooled Water-Cooled	Forced-Air-Cooled*	Forced Air-Cooled† or Forced-Oil-Cooled
Following 50-per-cent load or less	Figure 2	Figure 4	Figure 6
Following 100-per-cent load	Figure 3	Figure 5	Figure 7

Values between 50 and 100-per-cent load may be interpolated with sufficient accuracy.

*Forced-air-cooled rating is 133 per cent or less of self-cooled rating.

†Forced-air-cooled rating is over 133 per cent of self-cooled rating.

Guide for Loading Current-Limiting Reactors

See Interim Report on Overloading Current-Limiting Reactors, by transformer subcommittee of the AIEE committee on electric machinery.[1]

Application at Altitudes Greater Than 3,300 Feet (1,000 Meters)

Operation at Less Than Standard Ambient Temperatures

It is recognized as good practice to use apparatus of standard temperature rise at rated kilovolt-amperes at altitudes greater than 3,300 feet (1,000 meters), provided the temperature of the cooling air does not exceed the values for the respective altitudes given in Table VIII. Standard temperature limits will not be exceeded.

Obviously when advantage is taken of lower ambient temperatures at the higher altitudes to offset the increased temperature rise caused by decreased air density, the output cannot be increased to the full extent covered under "Loading on Basis of Ambient Temperature." For such loading the temperature base should be in accordance with Table VIII.

Operation at Standard Ambient Temperatures

It is recognized as good practice to use apparatus of standard temperature rise at altitudes greater than 3,300 feet (1,000 meters), provided the load to be carried is reduced below rating by the percentages given in Table IX for each 330 feet (100 meters) that the altitude is above 3,300 feet (1,000 meters). Standard temperature rise will not be exceeded.

Insulation

The dielectric strength of equipment which depends upon air for its insulation decreases as the altitude increases. The dielectric strength at 3,300 feet or less for a given insulation class should be multiplied by the proper altitude correction factor to obtain the dielectric strength at the required altitude (see Table X).

Table VI. Loading Pole-Type Constant-Current Transformers

Average Ambient Temperature, Degrees Centigrade	Period of Operation, Hours
30	8
25	10
20	12
15	14
10	16

Table VII. Loading Regulators

Starting at an Oil Temperature Corresponding to Continuous Operation at	Normal Life Expectancy, Per Cent		Moderate Sacrifice of Life Expectancy, Per Cent	
	1 Hr	2 Hr	1 Hr	2 Hr
Full load	0	0	35	30
1/4 load	20	14	50*	45
1/2 load	25*	17	50*	50*

*This load is the maximum that can be allowed, owing to hottest-spot temperature, vibration, torque, or contact-burning considerations on this class of equipment.

Appendix I. Calculations of Temperature and Loss of Life for Short-Time Loading of Transformers

Short-time loads above rating that use up different amounts of life expectancy for transformers having definite characteristics have been given in Figures 2 through 7. Generally, transformers included in these guides which have other characteristics will have greater load capabilities. This appendix gives information by which similar curves may be derived for such transformers.

In explaining the use of Figures 8 and 9 through 11, a self-cooled transformer having the same characteristics as those selected in the main portion of the guides, and having a load of 160 per cent for two hours following 50 per-cent load, is used as an example. The figures also apply to forced-air-cooled and forced-oil-cooled transformers.

Table VIII. Application at Altitudes Greater Than 3,300 Feet (1,000 Meters)

Method of Cooling Apparatus	Maximum Allowable Average Temperature of Cooling Air for Carrying Rated Kilovolt-Amperes, Degrees Centigrade			
	3,300 Ft (1,000 M)	6,600 Ft (2,000 M)	9,900 Ft (3,000 M)	13,200 Ft (4,000 M)
Oil-immersed self-cooled	30*	28	25	23
Oil-immersed forced-air-cooled	30*	26	23	20
Oil-immersed forced-oil-cooled with oil to air cooler	30*	26	23	20
Dry-type self-cooled				
Class-A insulation	30	27	24	21
Class-B insulation	30	26	22	18
Dry-type forced-air-cooled				
Class-A insulation	30	24	19	14
Class-B insulation	30	22	14	6

*See section 2.000 of American Standard C57.1 for explanation of average ambient temperature.

Characteristics at Rated Kilovolt-Amperes Required to Be Known	Example
1. Hottest-spot rise	65 C
2. Top-oil rise	45 C
3. Time constant at full load	3.0 hr
4. Ratio of copper to iron losses	2.5 to 1
5. Ambient temperature	30 C

Top-Oil Rise

1. Determine ultimate top-oil rise for initial load (50 per cent). On Figure 8 start at per cent or initial load (50) and go up to curve for ratio of losses (R=2.5). Go to left to line for full-load oil rise (45 degrees

centigrade). Go vertically and read ultimate oil rise (25 degrees centigrade).

2. Determine ultimate top-oil rise for short-time load in question. Repeat procedure in paragraph 1, starting at per-cent load in question (160) and read ultimate oil rise (82 degrees centigrade).

3. On Figure 9 set a straightedge at the initial oil temperature rise on the left scale (25 degrees centigrade) and at the ultimate oil temperature rise on the right scale (82 degrees centigrade). At the intersection of the line so determined and the vertical line through the intersection of lines for the desired time (two hours) and time constant (three hours), determine the oil temperature rise (52 degrees centigrade) at the end of the assumed time (two hours).

Hottest-Spot Copper Rise Over Top-Oil Temperature (Copper Gradient)

On Figure 10 start at per-cent load (160) on horizontal scale and go up to the curve for full-load hottest-spot rise (20 degrees centigrade). Go to left and read copper gradient (42 degrees centigrade) for the per-cent load in question (160 .

Hottest-Spot Copper Temperature

Obtain hottest-spot copper temperature by adding ambient temperature (30 degrees centigrade), top-oil rise (52 degrees centigrade), and hottest-spot rise (42 degrees centigrade), giving 124 degrees centigrade.

Per Cent Loss of Life

From Figure 11 obtain the loss of life (0.2 per cent) for the hottest-spot copper temperature (125 degrees centigrade) and the duration of the load (two hours). In calculating these curves it has been assumed that hottest-spot temperature is constant at its final value during the overload period. When this assumption is made, the elevated temperature during the cooling period need not be considered.

Table XI is suggested as a convenient method of tabulating values obtained by the foregoing procedure and covers values for the example assumed.

Appendix II. Formulas for Calculating Transient Heating of Oil-Immersed Transformers

List of Symbols

θ_a = ambient temperature (degrees centigrade)

θ_g = hottest-spot rise over top-oil temperature (degrees centigrade)

$\theta_{g(fl)}$ = hottest-spot rise over top-oil temperature at full load

θ_{hs} = hottest-spot temperature (degrees centigrade)

θ_o = top-oil rise over ambient temperature (degrees centigrade)

θ_{fl} = full-load top-oil rise (degrees centigrade)

θ_i = initial oil rise for $t=0$ (degrees centigrade)

θ_u = ultimate oil rise for load P (degrees centigrade)

Table IX. Application at Altitudes Greater Than 3,300 Feet (1,000 Meters)

Types of Cooling	Correction Factor, Per Cent
Oil-immersed self-cooled apparatus	0.4
Oil-immersed water-cooled apparatus	0.0
Oil-immersed forced-air-cooled apparatus	0.5
Oil-immersed forced-oil-cooled apparatus with oil to air cooler	0.5
Oil-immersed forced-oil-cooled apparatus with oil to water cooler	0.0
Dry-type self-cooled apparatus	0.3
Dry-type forced-air-cooled apparatus	0.5

Table X. Application at Altitudes Greater Than 3,300 Feet (1,000 Meters)

Altitude	Altitude Correction Factor A for Insulation Class
3,300 feet (1,000 meters)	1.00
4,000 feet (1,200 meters)	0.98
5,000 feet (1,500 meters)	0.95
6,000 feet (1,800 meters)	0.92
7,000 feet (2,100 meters)	0.89
8,000 feet (2,400 meters)	0.86
9,000 feet (2,700 meters)	0.83
10,000 feet (3,000 meters)	0.80
12,000 feet (3,600 meters)	0.75
14,000 feet (4,200 meters)	0.70
15,000 feet (4,500 meters)	0.67

Altitude of 15,000 feet is considered a maximum for standard apparatus.

P = ratio of load to full load

P_1 = ratio of equivalent initial load to full load (load which results in an ultimate rise of θ_i)

R = ratio of load loss to no-load loss

$\epsilon = 2.71828$

t = time load is applied in hours

B = thermal time constant of transformer for any load or any ratio of initial to ultimate oil temperature (hours)

B_r = time constant for full load beginning with initial temperature rise of 0 degrees (hours)

W_{fl} = total loss at full load (watts)

C = thermal capacity of transformer (watt-hours per pound per degree centigrade)

Hottest-Spot Temperature

The hottest-spot temperature

$$\theta_{hs} = \theta_a + \theta_o + \theta_g \qquad (1)$$

Transient heating and cooling equation for top-oil rise over ambient temperature

$$\theta_o = (\theta_u - \theta_i)(1 - \epsilon^{-\frac{t}{B}}) + \theta_i \qquad (2)$$

Ultimate top-oil rise for load P

$$\theta_u = \theta_{fl}[(P^2R+1)/(R+1)]^{0.8} \qquad (3)$$

Hottest-spot rise over top oil

$$\theta_g = \theta_{g(fl)} P^{1.6} \qquad (4)$$

$$\theta_{g(fl)} = \frac{\text{average copper rise over top oil}^* + \text{10 degrees centigrade}}{\text{Time constant at rated kilovolt-amperes}} \qquad (5)$$

*At rated kilovolt-amperes from manufacturer's test.

$$B_r = \frac{C\theta_{fl}}{W_{fl}} \qquad (6)$$

$C = 0.06$ (weight of core and coils) $+ 0.04$ (weight of tank) $+ 1.33$ (gallons of oil)

Theoretical Corrections for Preceding Formulas

Theoretically several corrections should be made in the foregoing formulas when one is calculating transient oil rises, such as corrections for change in:

1. Time constant for loads above rating.
2. Ultimate copper loss at end of load period.
3. Oil viscosity.

Practical Application of Formulas for Calculation of Oil Rises

In making general calculations based on assumptions of transformer characteristics and maximum hot-spot temperatures which generally have a large factor of safety, results close enough for all practical purposes are obtained if all of these corrections are omitted and the simpler formulas are used.

The overload values given in Figures 2 to 7 were calculated by the formulas without corrections.

1. Time Constant. The time constant is the length of time which would be required for the temperature of the oil to change from the initial value to the ultimate value if the initial rate of change were continued until the ultimate temperature was reached.

The time constant is usually the length of time required for a specified percentage of

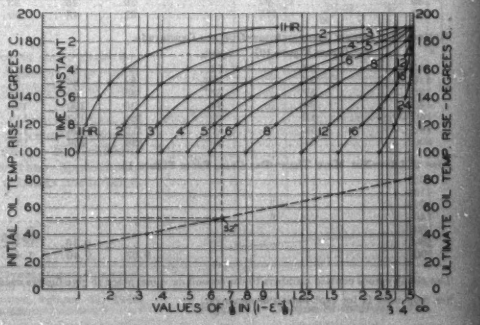

Figure 9. Top-oil temperature rise at end of specified load period

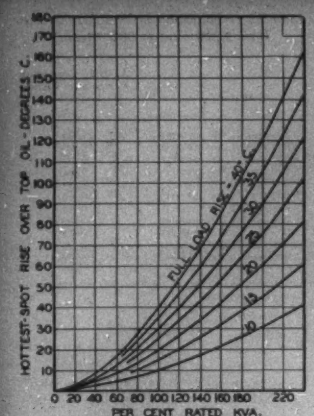

Figure 10. Hottest-spot copper rise over top-oil temperature

the change in temperature from initial value to ultimate value to take place.

If n^* equals unity, 63 per cent of the temperature change occurs in a length of time equal to the time constant, regardless of the relationship of initial temperature and ultimate temperature. If n is not unity, the percentage varies and is a function of both initial temperature rise and ultimate temperature rise. In particular, if n equals 0.8, the percentage is 67 if the initial temperature rise is zero.

If the initial temperature rise is greater than zero, the percentage is lower than 67 and decreases as the initial temperature rise increases for a given ultimate temperature rise. If the initial temperature is approximately equal to the final temperature, whether just above or just below it, the percentage is approximately 63. If the initial temperature is greater than the ultimate temperature, the percentage is less than 63.

Since evaluation of the exact percentage for cases where n is not unity and the initial temperature rise is not zero becomes very laborious, it is frequently advisable to use the value of 63 per cent as an approximation. In the more frequently encountered cases where n is approximately 0.8, the error resulting from this procedure is not large compared to the expected error in transient thermal calculations.

If $n=1.0$, equation 6 is correct for any load and any starting temperature. If n is less than 1.0, equation 6 holds only for full-rating starting cold. If $n=0.8$, the time constant for any load and for any starting temperature for either a heating cycle or cooling cycle is given by equations 7 and 8.

$$B=B_r\left[\frac{\dfrac{\theta_u}{\theta_{fl}}-\dfrac{\theta_i}{\theta_{fl}}}{\left(\dfrac{\theta_u}{\theta_{fl}}\right)^{1.25}-\left(\dfrac{\theta_i}{\theta_{fl}}\right)^{1.25}}\right] \qquad (7)$$

If starting cold ($\theta_i=0$) equation 7 reduces to

$$B=B_r\left(\frac{\theta_{fl}}{\theta_u}\right)^{0.25} \qquad (8)$$

*Exponential power of temperature rise versus loss.

2. Copper Loss. As the resistance of the copper for ultimate conditions is greater when the temperature is greater for loads above rating than for rated load conditions, a resistance correction factor should be added to equations 3 and 4.

3. Viscosity of Oil. The ultimate temperature rise of oil for a constant loss decreases slightly as the temperature of the oil increases, owing to a decrease in the viscosity of the oil. For hot-spot rise over oil the viscosity correction tends to offset the effect of increased resistance.

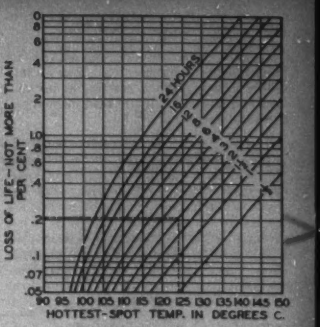

Figure 11. Hottest-spot copper temperature versus loss of life

Time, Hours	Temperatures in Degrees Centigrade to Use not More Than Following Life (Per Cent) 0.1	0.25	0.50	1.0
¼	132	142	150	
1	124	134	142	150
2	117	126	134	142
4	111	119	126	134
8	105	112	119	126
24	99	104	109	115

For explanation of degree of accuracy, see Appendix II.

Explanation of Degree of Accuracy of Figures 2 to 7 and Figure 11

The percentage loss-of-life values which will not be exceeded, shown on these figures, of necessity have been made quite conservative, as they depend on the rate of insulation

Table XI. Summary of Values Used in Plotting Figure 2

Per Cent Rated Kva	Ultimate Oil Rise	Hours Duration 0.5	1.0	1.5	2.0	3.0	4.0	6.0	8.0	12.0	16.0	24.0
Top Oil Rise—Degrees Centigrade (θ_o), From Figure 9												
105	48	28	31	34	36	39	42	45	47	47	48	48
110	51	28	32	35	37	41	44	47	49	50	51	51
120	56	29	33	37	40	44	48	53	54	55	56	56
140	68	31	36	42	46	53	57	63	65	68	69	69
160	82	34	41	47	53	61	67	74	78	81	82	82
180	97	36	45	53	60	71	78	87	92	96	97	97
200	113	37	48	59	66	80	89	101	107			
Hottest-Spot Copper Temperature—Degrees Centigrade												
	θ_x (From Figure 10) $\theta_x+\theta_o$						$\theta_{hs}=\theta_o+\theta_x+\theta_a$					
105	23 52	80	83	86	88	91	94	97	99	99	100	100
110	24 54	82	86	89	91	95	98	101	103	104	105	105
120	27 57	86	90	94	97	101	105	109	111	112	113	113
140	34 64	95	100	106	110	116	121	126	129	132	133	133
160	42 73	106	113	119	124	133	139	146	150	153	154	154
180	51 81	117	126	134	141	152	159					
200	61 91	128	139	150	157							
Loss of Life—Not More Than—Per Cent, From Figure 11												
105										0.05	0.07	0.11
110									0.08	0.13	0.18	0.27
120								0.12	0.21	0.38	0.53	0.80
140						0.14	0.30	0.76	1.43	2.49	3.60	5.40
160				0.10	0.22	0.78	1.65	4.70	8.40			
180			0.13	0.40	0.98	3.65	9.50					
200		0.07	0.40	1.45	3.90							

The above values contain numbers to the second decimal place to give figures used in plotting curves. No such high degree of accuracy in actual life loss is implied.

See Appendix II for explanation of symbols.

The Self-Inductance of a Toroidal Coil Without Iron

H. B. DWIGHT
FELLOW AIEE

IF A NONMAGNETIC BAR is bent into the shape of a ring and a single layer of wire is wound around the bar, the self-inductance of the "toroidal coil" formed in this way is given by well-known short expressions.

If the cross section of the nonmagnetic bar, that is, the cross section of the toroidal coil, is rectangular, the self-inductance is

$$L = 2hN^2 \log_n \frac{r_2}{r_1} \text{ abhenrys} \qquad (1)$$

where

h = axial length of the coil
r_1 = radius to inner face of the coil, centimeters
r_2 = maximum radius of the coil, centimeters
N = number of turns in the coil
$\log_n$ denotes natural logarithm

If the cross section of the toroidal coil is round, that is, if each turn is a circle, the self-inductance is

$$L = 4\pi N^2\left(R - \sqrt{R^2 - a^2}\right) \text{ abhenrys} \qquad (2)$$

where

R = mean radius of the complete ring
a = radius of a single turn, centimeters[1]

It was suggested to the writer by R. F. Field of the engineering department of the General Radio Company that a computation for inductance of a toroidal coil with a rectangular section and a comparatively thick winding would be useful.

In this paper is derived a formula for such a coil.

If, when the current in the wire is taken to be one abampere, the number of lines in each portion of magnetic flux is multiplied by the number of turns which it surrounds or links, the sum of such products or linkages is equal to the self-inductance of the coil in abhenrys.

Let the thickness of the winding on the inner side of the coil be t_1 (see Figure 1). Then

$$r_1 = r_1 - t_1$$

$$\text{Length of element } dx = h + (h_1 - h)\frac{(r_1 - x)}{t_1}$$

$$= h + (h_1 - h)\frac{r_1}{t_1} - (h_1 - h)\frac{x}{t_1}$$

Let it be assumed that the wire follows along dx and has a sharp corner when it goes to the right, instead of a rounded corner.

Let the density of turns per square centimeter be n, a constant depending on the size of wire and the amount of insulation.

$$n = \frac{N}{\pi(r_1^2 - r_2^2)} \qquad (3)$$

Also

$$t_1 = \frac{N}{2\pi r_1 n} \qquad (4)$$

since the wires cross the axial line t_1 practically at right angles. Similarly,

$$t_2 = \frac{N}{2\pi r_2 n} \qquad (5)$$

The dimension h_1, Figure 1, is found by drawing a straight line through the ends of t_2 and t_1.

$$h_1 = h + 2\left\{t_1 + \frac{(w + t_1)(t_2 - t_1)}{w}\right\} \qquad (6)$$

Turns linking element dx are

$$T_{(x)} = \pi n(x^2 - r_1^2)$$

$$\text{Flux density at } dx = \frac{4\pi T_{(x)}}{2\pi x} = \frac{2T_{(x)}}{x}$$

Linkages for flux in element dx are

$$\text{Flux density} \times T_{(x)} \times \left\{h + (h_1 - h)\frac{r_1}{t_1} - (h_1 - h)\frac{x}{t_1}\right\} dx$$

$$= \frac{2\pi^2 n^2}{x}(x^4 - 2x^2 r_1^2 + r_1^4)(h + pr_1 - px)dx$$

$$= \frac{2\pi^2 n^2}{x}\left\{-px^3 + (h + pr_1)x^4 + 2pr_1^2 x^2 - 2(h + pr_1)r_1^2 x^2 - pr_1^4 x + (h + pr_1)r_1^4\right\} dx$$

where

$$p = \frac{h_1 - h}{t_1} \qquad (7)$$

Integrate from $x = r_1$ to r_2.
Linkages due to flux in the inner trapezoid of base h_1 (Figure 1) are

$$2\pi^2 n^2\left[-\frac{px^3}{5} + (h + pr_1)\frac{x^4}{4} + 2pr_1^2\frac{x^3}{3} - (h + pr_1)r_1^2 x^2 - pr_1^4 x + (h + pr_1)r_1^4 \log_n x\right]_{x=r_1}^{r_2} \qquad (8)$$

The triangle ABC, Figure 1, is filled with wires that are nearly horizontal. The linkages of the magnetic flux in ABC are about one per cent of the total for the coil in the example given. To simplify the computation of this part, the triangle ABC can be replaced by the triangle ADC. These triangles have the same

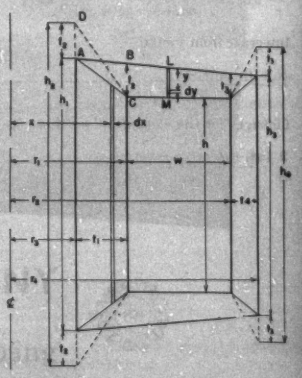

Figure 1. Section of toroidal coil

Paper 45-159, recommended by the AIEE committee on basic sciences for publication in AIEE TRANSACTIONS. Manuscript submitted July 24, 1945; made available for printing August 27, 1945.

H. B. DWIGHT is professor of electric machinery, Massachusetts Institute of Technology, Cambridge, Mass.

deterioration occuring at various temperatures.

Transformer life expectancy with continuous operation at 95 degrees centigrade is not known, but past experience indicates that the life is satisfactory. As a basis for these tables, operation at 115 degrees centigrade for 24 hours has been assumed to give not over one-per-cent loss of insulation life, as determined by tensile strength.

Information given is considered to be the best that can be produced from the present knowledge of the subject. In spite of its approximate nature, it is believed that it will be of much value to the industry as a guide.

The subject of insulation life is receiving the continuous attention of the transformer subcommittee. New findings may make future revision and modification of these guides necessary.

The transformer subcommittee does not recommend that any particular transformer life expectancy be assumed. It specifically points out that more than approximate accuracy in loss of life values is not implied.

Reference

1. INTERIM REPORT ON OVERLOADING CURRENT-LIMITING REACTORS, AIEE transformer subcommittee. AIEE TRANSACTIONS, volume 62, 1943, October section, pages 611–12.

area, as they have the same height l_1, and equal bases $AD=BC=l_2$. In both triangles the flux density is 0 along the side AD or AB and increases toward the vertex C and so the triangle ADC, treated as an extension of the trapezoid of base h_1, gives a close approximation to the linkages of triangle ABC.

Therefore, instead of computing equations 7 and 8, take

$$h_2=h_1+2l_2 \tag{9}$$

$$q=\frac{h_2-h}{l_1} \tag{10}$$

and linkages due to flux in the enlarged trapezoid of base h_2 are

$$2\pi^2n^2\left[-\frac{qx^5}{5}+(h+qr_1)\frac{x^4}{4}+\frac{2}{3}qr_2{}^2x^3-(h+qr_1)r_2{}^2x^2-qr_2{}^4x+(h+qr_1)r_2{}^4\log n\ x\right]_{x=r_2}^{r_1}$$

$$=2\pi^2n^2\left[(h+qr_1)\left(r_2{}^4\log n\frac{r_1}{r_2}-r_2{}^2l_1+\frac{1}{2}r_2{}^2l_1{}^2+r_2l_1{}^3+\frac{1}{4}l_1{}^4\right)-ql_1{}^4\left(\frac{4}{3}r_2{}^2+r_2l_1+\frac{1}{5}l_1{}^2\right)\right] \tag{11}$$

since $r_1=r_2+l_1$.

Consider a vertical elementary strip LM of width dx, at a distance x from the axis.

$$LM=l_1+(l_2-l_1)\frac{(r_2-x)}{w}=\frac{wl_1+(l_2-l_1)(r_2-x)}{w}$$

The turns which link the flux in $dxdy$ are

$$T=\frac{y}{LM}N=\frac{wyN}{wl_1+(l_2-l_1)(r_2-x)}$$

Flux density at $dxdy=\dfrac{2T}{x}$

Linkages of the flux in $dxdy$ are

$$\frac{2T^2}{x}\,dxdy=\frac{2}{x}\frac{w^2y^2N^2}{\{wl_1+(l_2-l_1)(r_2-x)\}^2}\,dxdy$$

Integrate from $y=0$ to

$$\frac{wl_1+(l_2-l_1)(r_2-x)}{w}$$

Linkages for the element of width dx are

$$\frac{2}{3x}\frac{\{wl_1+(l_1-l_1)(r_2-x)\}^3N^2}{w}\,dx$$

Integrate from $x=r_1$ to r_2 and multiply by 2.

Linkages for the trapezoids at the ends of the coil

$$=\frac{4N^2}{3w}\left[\{wl_1+r_2(l_2-l_2)\}\times\log n\ x-x(l_2-l_1)\right]_{x=r_1}^{r_2}$$

$$=\frac{4N^2}{3}\left[\left\{l_2+\frac{r_2(l_2-l_2)}{r_2-r_1}\right\}\log n\frac{r_2}{r_1}-(l_2-l_2)\right] \tag{12}$$

For the outer trapezoid of the coil section, Figure 1,

$$s=\frac{N}{\pi(r_4{}^2-r_3{}^2)} \tag{13}$$

from which r_4 and l_4 may be found.

Note that measured values of l_2, l_3, and l_4 may be used instead of values computed on the basis of constant density of turns.

The length of a vertical element at radius x in the outer trapezoid is

$$h+\frac{x-r_3}{l_4}(h_2-h)=h-(h_2-h)\frac{r_3}{l_4}+(h_2-h)\frac{x}{l_4}$$

where

$$h_2=h+2\left\{l_3-\frac{l_4}{w}(l_2-l_2)\right\} \tag{14}$$

Turns linking the element at radius x are

$$T_{(x)}=\pi n(r_4{}^2-x^2)$$

Flux density at $dx=\dfrac{2T_{(x)}}{x}$

Linkages for flux in element of width dx are

$$\text{Flux density}\times T_{(x)}\times\left\{h-(h_2-h)\frac{r_3}{l_4}+(h_2-h)\frac{x}{l_4}\right\}dx$$

$$=\frac{2\pi^2n^2}{x}(x^4-2x^2r_4{}^2+r_4{}^4)(h-p_1r_3+p_1x)dx$$

$$=\frac{2\pi^2n^2}{x}\{p_1x^5+(h-p_1r_3)x^4-2p_1r_4{}^2x^3-2(h-p_1r_3)r_4{}^2x^2+p_1r_4{}^4x+(h-p_1r_3)r_4{}^4\}dx$$

where

$$p_1=\frac{h_2-h}{l_4}$$

Integrate from $x=r_3$ to r_4. Linkages for flux in trapezoid of base h_2 are

$$2\pi^2n^2\left[\frac{p_1x^6}{5}+(h-p_1r_3)\frac{x^4}{4}-\frac{2}{3}p_1r_4{}^2x^3-(h-p_1r_3)r_4{}^2x^2+p_1r_4{}^4x+(h-p_1r_3)r_4{}^4\log n\ x\right]_{x=r_3}^{r_4}$$

In order to include the effect of the two outer triangles, change h_2 to

$$h_4=h_2+2l_2 \tag{15}$$

Then

$$q_1=\frac{h_4-h}{l_4} \tag{16}$$

Linkages for flux in the enlarged trapezoid of base h_4 are

$$2\pi^2n^2\left[(h-q_1r_3)\left(\frac{4}{3}r_4l_4{}^3+\frac{1}{5}\frac{l_4{}^5}{r_4}+\frac{1}{6}\frac{l_4{}^6}{r_4{}^2}+\dots\right)+q_1l_4{}^3\left(\frac{4}{3}r_4{}^2-r_4l_4+\frac{1}{5}l_4{}^2\right)\right] \tag{17}$$

since $r_3=r_4-l_4$, and l_4 is small compared with r_4.

The self-inductance of the coil in abhenrys is given by the sum of formulas 1, 11, 12, and 17.

Example. The following coil was constructed and measured by R. F. Field. If centimeter dimensions are used,

$r_1=2.54$, $r_2=7.62$, $r_3=0.698$
$r_4=8.23$, $l_3=1.173$, $l_2=0.635$
$h=12.7$, $N=1{,}680$

According to these dimensions, the density of the turns in the inner and outer parts is different.

$w=r_2-r_1=5.08$
$l_1=r_1-r_3=1.842$
$h_1=15.44$, $h_2=17.78$, $q=2.76$, $h+qr_1=19.71$
Linkages for the rectangle $=wh=78.8\times10^8$
Linkages for enlarged inner trapezoid of Figure $1=17.0\times10^8$
Linkages for the two end trapezoids $=3.9\times10^8$
Linkages for enlarged outer trapezoid $=2.0\times10^8$
Inductance of coil $=(78.8+17.1+3.9+2.0)10^8$ abhenrys $=0.1018$ henry

The measured value agreed with this within less than one per cent.

Reference

1. THEORY OF ALTERNATING CURRENTS, Alexander Russell. Edition of 1914, page 74.

KERITE Self-supporting Aerial Cable

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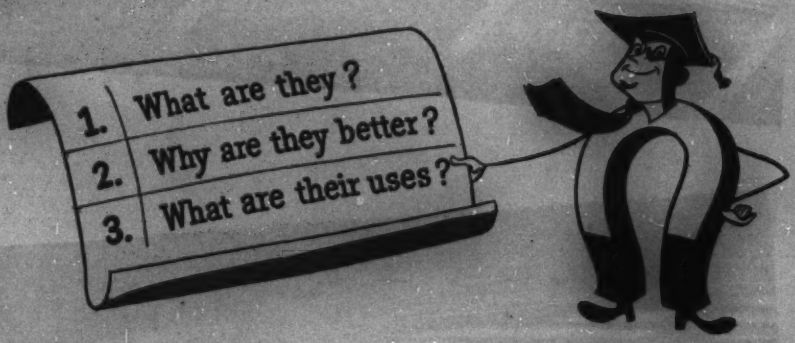
The 3 "most-asked" questions about Carbonyl Iron Powders



For wartime uses, design engineers asked these three questions.

In peacetime, as design engineers plan for peacetime equipment, the same questions are asked.

"What are they?"

G.A.F. Carbonyl Iron Powders are obtained by thermal decomposition of iron penta-carbonyl. There are five different grades in production, designated as "L," "C," "E," "TH," and "SF" Powder. Each of these five types of iron powder is obtained by special processing methods and has its special field of application.

The particles making up the powders "E," "TH," and "SF" are spherical with a characteristic structure of concentric shells. The particles of "L" and "C" are made up of homogeneous spheres and agglomerates.

Their weight-average diameter, their total iron contents, and their carbon contents are given in the table at upper right.

"Why are they better?"

Carbonyl Iron Powders are better because of their unique spherical shape, shell structure, particle size distribution, high degree of purity and freedom from stress.

Their stability against magnetic shock, temperature changes, and time (aging) is of the highest order.

Permeabilities range up to 70 with low eddy-current losses. Q values are the highest obtainable because of extremely small eddy-current and hysteresis losses.

Carbonyl Iron Powders are better as electromagnetic material over the entire communication frequency spectrum.

A set of relative Q values for the five powder grades is given in the graph on the other page to show the conventional frequency range for each grade.

"What are their uses?"

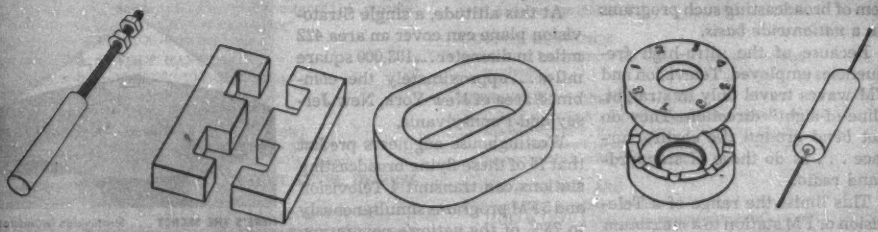
Carbonyl Iron Powders are used for electromagnetic cores and structures for widely different purposes. Five typical applications are shown on the chart at bottom of other page.

"L" and "C" powders are also used as powder metallurgical material because of their low sintering temperatures, high tensile strengths, and other very desirable qualities. Sintering begins below 500°C and tensile strengths reach 150,000 psi. Compacts can be made having regular pronounced porosity to function as a spongy mass. Compacts can also be made of highest density for excellent magnetic properties.

Further information can be obtained from the Special Products Sales Dept., General Aniline & Film Corporation, 270 Park Avenue, New York 17, N. Y.

Diameters and Chemical Composition of the 5 Carbonyl Iron Powder Grades

Carbonyl Iron Grade	Weight-Average Diameter Microns	Total Fe Content %	Total Carbon Content %
L	20	99.7-99.9	0.005-0.03
C	10	99.5-99.8	0.03 -0.12
E	8	97.9-98.3	0.65 -0.80
TH	5	98.1-98.5	0.5 -0.6
SF	3	98.0-98.3	0.5 -0.6



"L" Type Powder used in cores for permeability tuning.

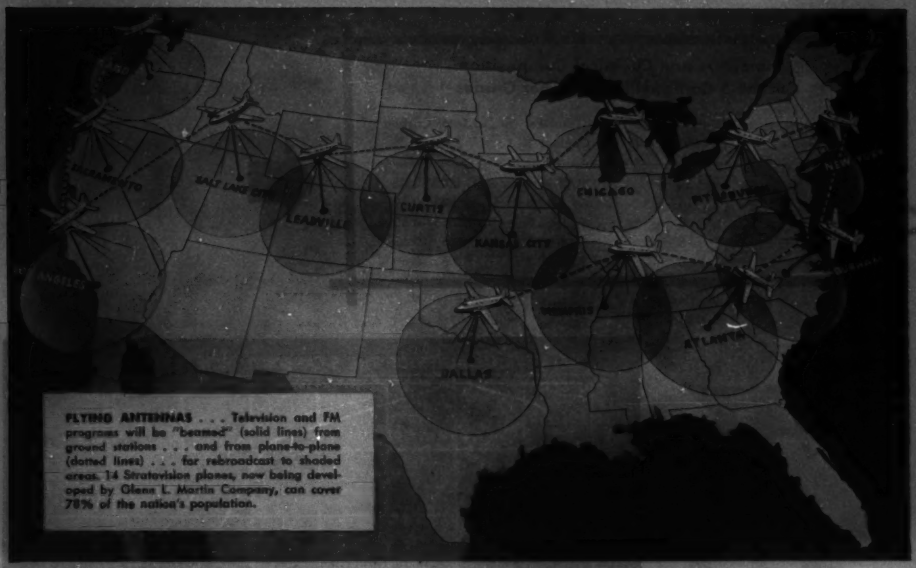
"C" Type Powder for E-cores in filter coils.

For antenna coils, "E" Type Powder used in cores.

"TH" Type Powder is employed for cup shields in coils.

One use of "SF" Type Powder is in high frequency choke cores (with sealed-in leads).

G.A.F. CARBONYL IRON POWDERS



FLYING ANTENNAS . . . Television and FM programs will be "beamed" (solid lines) from ground stations . . . and from plane-to-plane (dotted lines) . . . for rebroadcast to shaded areas. 14 Stratovision planes, now being developed by Glenn L. Martin Company, can cover 78% of the nation's population.

How Westinghouse STRATOVISION took the final headache out of Television and FM

EVEN before the war ended, Television and FM transmitting and receiving equipment had reached a high degree of perfection. But a final difficulty remained—the problem of broadcasting such programs on a *nationwide basis.*

Because of the ultra-high frequencies employed, Television and FM waves travel only in straight, "line-of-sight" direction. They do not *bend* around the earth's surface . . . as do those of standard-band radio..

This limits the range of a Television or FM station to a *maximum of 50 miles*—even when perched atop the tallest building.

A chain of radio-relay stations across the country—or coaxial cables spanning the nation—have been proposed as a solution. But these are terrifically expensive and, worse yet, cause serious distortion of long distance programs.

Now, at last, Westinghouse research engineers have discovered a practical solution through "STRATOVISION"—broadcasting Television and FM programs from *planes flying six miles high in the stratosphere!*

At this altitude, a single Stratovision plane can cover an area 422 miles in diameter . . . 103,000 square miles . . . approximately the combined area of New York, New Jersey and Pennsylvania.

Westinghouse engineers predict that 14 of these flying broadcasting stations can transmit 4 Television and 5 FM programs simultaneously to *78% of the nation's population.*

The conception and planning of Stratovision broadcasting are a tribute to the ingenuity and engineering "know-how" of Westinghouse radio technicians . . . gained through producing $400,000,000 worth of Radar and radio equipment for our armed forces.

HERE'S THE SECRET . . . Stratovision broadcasting, serving an area of 103,000 square miles, will require only *1/50th as much power* as a 50 kilowatt ground transmitter covering only 7,900 square miles. That's why a *single Stratovision plane* can easily carry and power the equipment needed for simultaneously transmitting 4 Television and 5 FM programs.

Westinghouse

PLANTS IN 25 CITIES — OFFICES EVERYWHERE

Tune in: JOHN CHARLES THOMAS—Sunday, 2:30 pm, EST, NBC.
TED MALONE—Monday through Friday, 11:45 am, EST, American Network

LONG SCALE, WIDE RANGE VOLT-OHM-MILLIAMMETER

DOUBLE SENSITIVITY D. C. VOLT RANGES
0-1.25-5-25-125-500-2500 Volts, at 20,000 ohms per volt for greater accuracy on Television and other high resistance D.C. circuits.
0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

A. C. VOLT RANGES
0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

OHM-MEGOHMS
0-400 ohms (60 ohms center scale)
0-50,000 ohms (300 ohms center scale)
0-10 megohms (60,000 ohms center scale)

DIRECT READING OUTPUT LEVEL DECIBEL RANGES
−30 to +3, +15, +29, +43, +55, +69 DB

TEMPERATURE COMPENSATED CIRCUIT FOR ALL CURRENT RANGES D.C. MICROAMPERES
0-50 Microamperes, at 250 M.V.

D. C. MILLIAMPERES
0-1-10-100-1000 Milliamperes, at 250 M.V.

D. C. AMPERES
0-10 Amperes, at 250 M.V.

OUTPUT READINGS
Condenser in series with A.C. Volts for output readings.

ATTRACTIVE COMPACT CASE
Size: 2½" x 5½" x 6". A readily portable, completely insulated, black, molded case, with strap handle. A suitable black, leather carrying case (No. 629) also available, with strap handle.

LONG 5° SCALE ARC
For greater reading accuracy on the Triplett RED ● DOT Lifetime Guaranteed meter.

SIMPLIFIED SWITCHING CIRCUIT
Greater ease in changing ranges.

Write for descriptive folder giving full technical details

Precision first ...to last

Triplett

TRIPLETT

ELECTRICAL INSTRUMENT CO. BLUFFTON, OHIO

IRVINGTON

with Fibron

EXTRUDED TUBINGS AND TAPE
of low-loss

POLYETHYLENE* and POLYTHENE**

Irvington now offers these new thermo-plastic materials, in extruded and calendered tape forms, for use as insulation where high frequencies are involved and applications where exceptional chemical and moisture resistance are required.

For electrical insulation . . . superior low-loss electrical properties, low moisture absorption, and high resistance to ozone, oil, acids and alkalis, make Polyethylene and Polythene ideal for high frequency applications and other special requirements as well.

For chemical applications . . . Both Polyethylene and Polythene are highly resistant to the halogen group including fluorine . . . offer the low density and other properties of paraffin, *plus* superior mechanical strength and higher melting points, can be formed and reformed in service as desired.

Samples and complete cooperation on your problems are freely offered. Write Dept. 106.

IRVINGTON

CLIP-ON AMMETER

LOW COST
DUAL RANGE
0-100/500 Amps

MULTI RANGE
0-10/25/100/250/1000 A

both with
Bakelite Enclosed Core
Large Window
12 Yrs. Proven Service

FERRANTI ELECTRIC, INC.

"first—"

AGAIN, AS IN THE PAST, SIMPLEX COMES UP WITH ANOTHER *first* THIS TIME WITH FLAME - RESISTING TIREX PORTABLE CABLES.

ALL TIREX CABLES ARE NOW *Flame* RESISTING

In addition to the famous Selenium Rubber Armor which protects all Simplex-TIREX cables, flame-resistance has been added to the Selenium Rubber Armor with no reduction in its wearing quality.

TIREX SELENIUM Rubber Armor

When you need portable cables again, remember that Simplex-TIREX cables combine the latest advances in both manufacturing and technical skill.

THE BEST THINGS IN CABLE CONSTRUCTION COME FROM SIMPLEX FIRST

Simplex Wire & Cable Co., 79 Sidney Street, Cambridge 39, Mass.

Simplex WIRES and CABLES

that Waldes Truarc Retaining Rings hold moving parts together better!

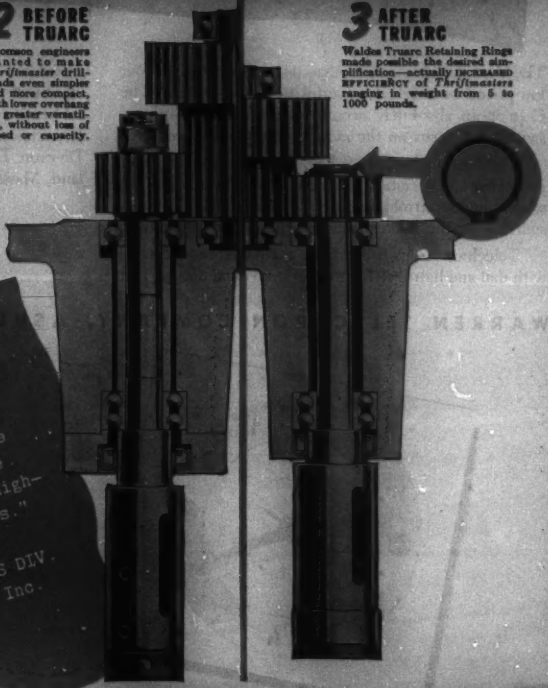
1 Waldes Truarc Retaining Rings saved Thomson Industries up to 10% in overall dimensions on their well-known *Thrift*master multiple spindle drillheads.

2 BEFORE TRUARC

Thomson engineers wanted to make *Thrift*master drillheads even simpler and more compact, with lower overhang for greater versatility, without loss of speed or capacity.

3 AFTER TRUARC

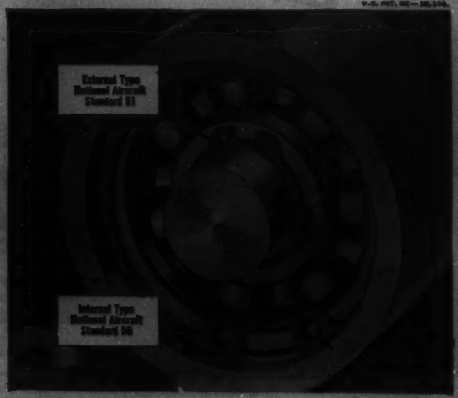
Waldes Truarc Retaining Rings made possible the desired simplification—actually INCREASED EFFICIENCY of *Thrift*masters ranging in weight from 5 to 1000 pounds.



"Waldes Truarc Retaining Rings enabled us to make substantial time and labor savings in production of THRIFTMASTER drillheads...and made possible a much lighter, handier, more rugged tool, exceeding our high-est performance requirements."

(Signed)
THRIFTMASTER PRODUCTS DIV.
Thomson Industries, Inc.

IN HOLDING and positioning machine parts, Waldes Truarc Retaining Rings offer distinct advantages over nuts, shoulders, collars and pins. They save cost by simplifying and speeding up production. They make assembly and disassembly much quicker, easier. They can be put on and taken off time and time again—and still retain the perfectly true circularity that gives them their never-failing grip. Test Waldes Truarc Retaining rings in your products and in the machines that make them. We'll furnish samples and complete data. Write Dept. F-11.



WALDES TRUARC TRADE MARK **RETAINING RING**

WALDES KOHINOOR, INC., LONG ISLAND CITY 1, NEW YORK

CANADIAN REPRESENTATIVES: PRODUCTS PROGRESS CORP., LTD., 72-76 STAFFORD STREET, TORONTO

A TELECHRON SWITCH CLOCK MAKES YOUR RADIO AN ALARM

The C-40 Telechron electric radio switch clock gives your low-priced bedside set powerful new sales appeal. The C-40 is an absolutely accurate electric clock — plus a switch that turns on the radio at any pre-selected time.

The cost of the C-40 is low. Installation is easy and inexpensive. Operation is simple, too. The alarm is set with a single control knob to the desired time. The clock switches on the radio to awaken the owner with music.

Telechron C-40 is available for panel mounting — with dial and hands styled to your individual needs. The precision-built Telechron synchronous motor guarantees absolutely accurate time. And the exclusive, sealed-in lubrication system assures years of dependable, trouble-free service. For full details, write or wire Industrial Sales Division, Dept. E, Warren Telechron Company, Ashland, Massachusetts.

Telechron

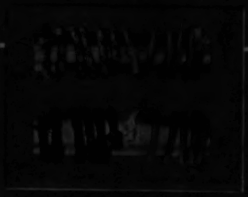
REG. U. S. PAT. OFF.

WARREN TELECHRON COMPANY, ASHLAND, MASSACHUSETTS

DC

SILICONES

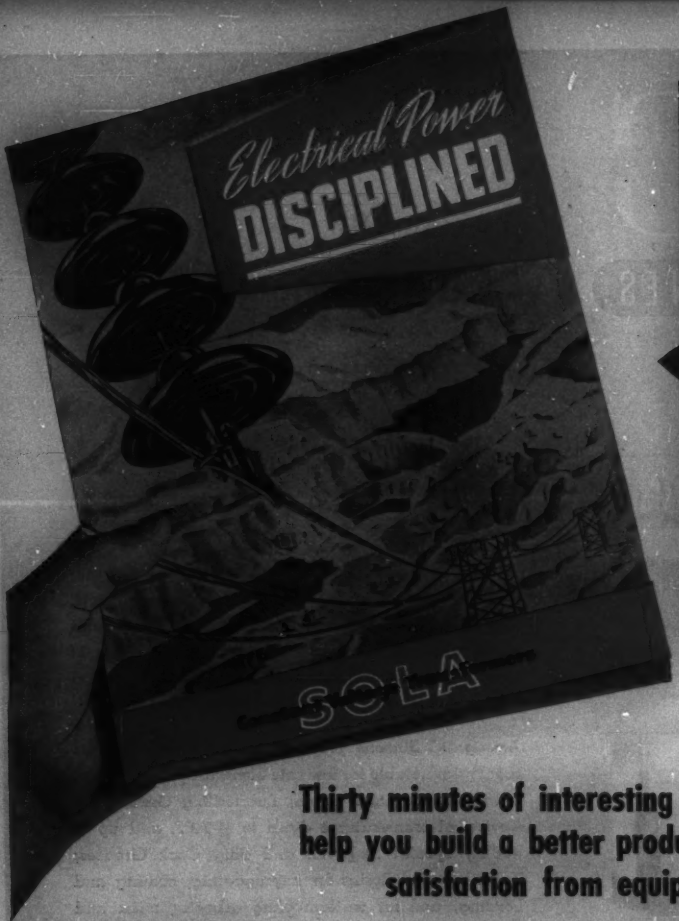
revise old concepts of the properties of materials



DOW CORNING CORPORATION
MIDLAND, MICHIGAN

Dow Corning

FIRST IN SILICONES



for:

designers

•

manufacturers

•

maintenance engineers

•

salesmen

•

users of electronic and electrically operated equipment

Thirty minutes of interesting reading that will help you build a better product or get greater satisfaction from equipment now in use

What is a Constant Voltage Transformer?—why is it necessary?—how does it operate?—where can it be used?—what new developments have resulted from its world-wide, war-time use?—

. . . these and many other important questions are fully answered in this new SOLA handbook.

The Constant Voltage Transformer is an exclusive SOLA product—the ONLY voltage regulating TRANSFORMER. In principle, design and construction it is different and should not be confused with ordinary types of voltage regulating networks.

It employs no tubes and has no moving parts. It is fully automatic in operation, it is not dependent on manual control or supervision and protects both itself and the equipment it serves against voltage surges or short circuit. It instantly corrects voltage fluctuations as great as 30% to within ±1% of rated value.

Your product will serve more people—*better*—with built-in Constant Voltage. There are SOLA units specially designed for that purpose—fully described in this new handbook.

Write for your copy

You will find in this handbook a final answer to the problem that confronts every manufacturer or user of electrically operated equipment.

Ask for Bulletin ACV-102

SOLA Constant Voltage Transformers

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • etc. **SOLA ELECTRIC COMPANY, 2525 Clybourn Avenue, Chicago 14, Illinois**

OHMITE
Rheostats and Resistors
IN PRODUCTION OF
Penicillin

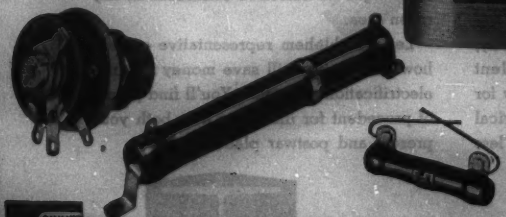
USED IN
ELECTRONIC POWER GENERATOR
that dries Penicillin 48 times faster

● A new RCA electronic system, using high frequency current for the bulk reduction of purified Penicillin, accomplishes in 30 minutes what formerly took 24 hours.

In the RCA Electronic Power Generator are six Ohmite resistors and two Ohmite rheostats. Circled in the photo above are a 200 watt regulator plate resistor, two 200 watt cathode bias resistors for the two power tubes, and a 50 watt rheostat used as a cathode balancer. Not visible in the photo are two 10 watt Brown Devil resistors used for voltage dropping in the pilot light circuits, one 10 watt Brown Devil in a time delay relay circuit, and a 50 watt rheostat used as the output power control.

The use of Ohmite products in such vital electronic equipment is further proof of their complete reliability.

OHMITE MANUFACTURING COMPANY
4802 FLOURNOY STREET, CHICAGO 44, U. S. A.



Write on company letterhead for Industrial Catalog and Engineering Manual No. 40. Addres Ohmite Mfg. Co., 4802 Flournoy St., Chicago 44

Be Right with OHMITE
RHEOSTATS · RESISTORS · TAP SWITCHES

Ruralductor came to stay.

By filling a definite need, this stranded steel conductor has proved itself during the war years. It will be doing a still bigger job in the era of peaceful tomorrows.

Comparative figures have proved beyond question that Ruralductor effects outstanding economies where secondary feeders and tap mileage predominate. Being of steel, Ruralductor possesses the strength that makes possible longer spans, hence a reduction in the number of pole structures needed.

That is the reason for its basic economy, since a non-ferrous line of equivalent strength would be unnecessarily costly for most rural mileage. Ruralductor's electrical capacity, while of course somewhat less than that of non-ferrous conductors, is entirely adequate for most farm districts not yet electrified.

As a protection against corrosion, Ruralductor is bethanized—guarded against corrosive action by a smooth, uniform zinc armor of high purity. The bethanizing process, used exclusively by Bethlehem, creates coatings in three different weights—A, B, and C. This is a distinct advantage, as it enables the user to select the proper coating weight for corrosive conditions in any given area.

Let a Bethlehem representative explain how Ruralductor will save money in farm-electrification programs. You'll find plenty of precedent for including it in both your present and postwar planning.

TINY GIANT WITH A HISTORY

Long before the war, the men who design your Bell Telephone System were looking for an electron tube with frequency capabilities never before attained. With it, they could transmit wide bands of telephone messages — several hundred of them — simultaneously through coaxial cable—economically, and over long distances.

They developed a tube which set a new standard in broad-band, high-frequency amplification. So minute that its electrode system had to be inspected under a magnifying glass, the tube could amplify either the voices of 480 people talking at the same time, or the patterns of television. Long-distance, broad-band transmission became a commercial reality.

6AK5

Cross-section of Electrode System (five times actual size)

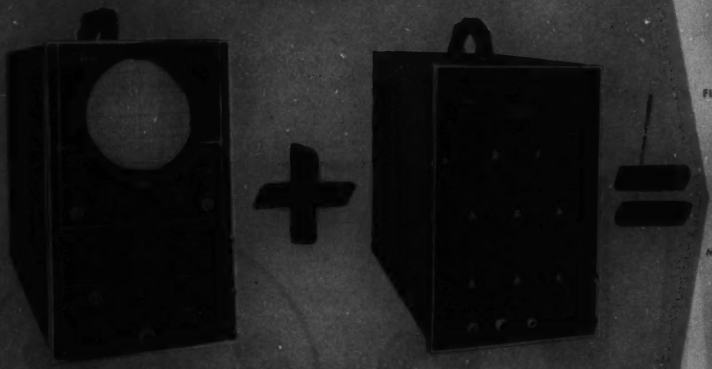
When war came, this tube excelled all others as an amplifier in certain military equipment. It then grew into the 6AK5, one of the great little tubes of the war. Besides producing 6AK5's in large quantities, the Western Electric responded to emergency needs of the Army and Navy by furnishing design specifications and production techniques to other manufacturers, of whom at least five reached quantity production. On every battlefront it helped our ships and planes to bring in radio signals.

Developing electron tubes of revolutionary design has been the steady job of Bell Laboratories scientists ever since they devised the first practical telephone amplifier over thirty years ago. Now tubes like the 6AK5 will help speed the living pictures of television, as well as hundreds of telephone conversations simultaneously over the coaxial and radio highways of the Bell Telephone System.

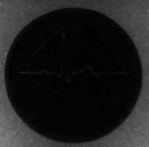
BELL TELEPHONE LABORATORIES

Exploring and inventing, devising and perfecting for continued improvements and economies in telephone service.

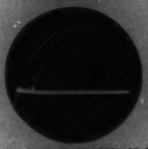
Does your oscillograph have single or recurrent sweep frequencies as low as 0.2 cycles per second? *IT CAN . . .*



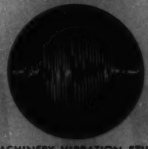
with the DuMONT Type 215 LOW-FREQUENCY LINEAR-TIME-BASE GENERATOR



ELECTROCARDIOGRAPHY



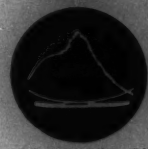
FLASH BULB CHARACTERISTICS



MACHINERY VIBRATION STUDY

ELECTROENCEPHALOGRAPHY

RELAY REBOUNCE STUDY



DIESEL ENGINE CYLINDER PRESSURE

Here's the means for *vastly increasing* the usefulness of your already useful oscillograph.

This accessory instrument provides a 450 v. d.c. or peak-to-peak *undistorted* linear-time-base signal voltage of a frequency variable from 0.2 to 125 cycles per second! Special compensating circuit assures linearity.

The single sweep can be initiated either manually or by observed signal. The oscillograph-screen pattern can usually be spread out to three times' full scale deflection. Return trace blanking signal of either positive or negative phase.

• • •

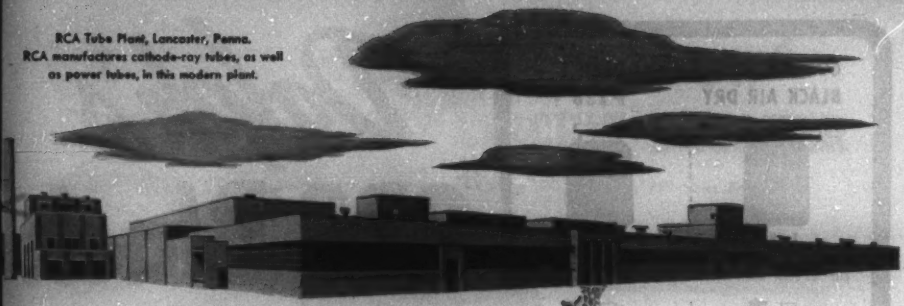
For single sweep, and for low-frequency recurrent-sweep studies, the DuMont Type 215 Low-Frequency Linear-Time-Base Generator used in combination with the DuMont Type 208-B general purpose oscillograph, or equivalent, provides excellent results. Note the typical studies herewith. Definitely "must" equipment.

Descriptive literature on request.

© ALLEN B. DUMONT LABORATORIES, INC.

DUMONT *Precision Electronics & Television*

ALLEN B. DUMONT LABORATORIES, INC. PASSAIC, NEW JERSEY • CABLE ADDRESS: WESPEXLIN, NEW YORK



RCA Tube Plant, Lancaster, Penna.
RCA manufactures cathode-ray tubes, as well as power tubes, in this modern plant.

Last year the production of

POWER TUBES

by the Tube Division of RCA

was greater than that of

any other manufacturer in the world

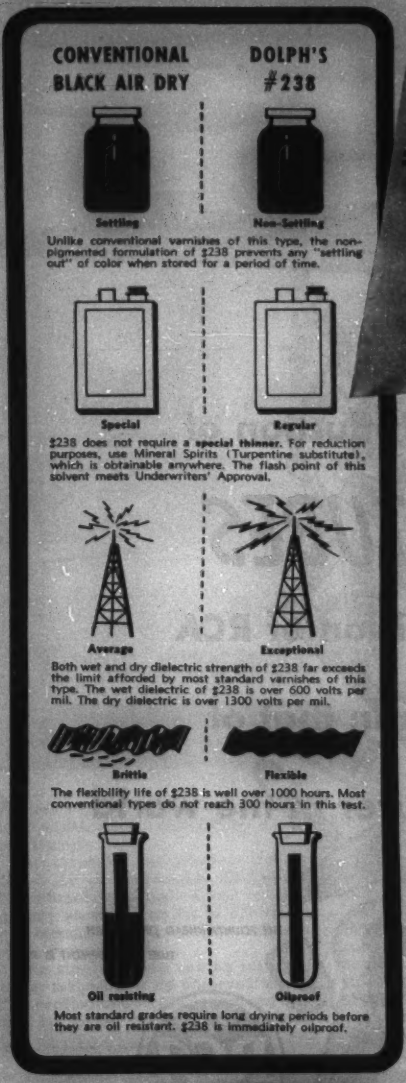
THE FOUNTAINHEAD OF MODERN TUBE DEVELOPMENT IS RCA

RCA

RADIO CORPORATION OF AMERICA

TUBE DIVISION • HARRISON, N. J.

Dolph's #238 Black AIR DRYING VARNISH


CONVENTIONAL BLACK AIR DRY
DOLPH'S #238
Settling
Non-Settling
Unlike conventional varnishes of this type, the non-pigmented formulation of #238 prevents any "settling out" of color when stored for a period of time.
Special
Regular
#238 does not require a special thinner. For reduction purposes, use Mineral Spirits (Turpentine substitute), which is obtainable anywhere. The flash point of this solvent meets Underwriters' Approval.
Average
Exceptional
Both wet and dry dielectric strength of #238 far exceeds the limit afforded by most standard varnishes of this type. The wet dielectric of #238 is over 600 volts per mil. The dry dielectric is over 1300 volts per mil.
Brittle
Flexible
The flexibility life of #238 is well over 1000 hours. Most conventional types do not reach 300 hours in this test.
Oil resisting
Oilproof
Most standard grades require long drying periods before they are oil resistant. #238 is immediately oilproof.

Realizing the ever present need for an outstanding black, flexible oil-proof finishing varnish, the DOLPH Laboratories, backed by their long years of experience and research, have created, and now make available to you, a new black air drying varnish . . . #238. We definitely feel that this product with all its exceptional attributes, is timely and worthy of your attention.

In addition to the advantages already illustrated, #238 possesses the following characteristics, all included in its formulation to produce better results for you . . . a non-fading opacity which permits excellent hiding power and coverage . . . the slow initial set of this grade affords ultimate ease in application, whether brushing, dipping or spraying, and also provides uniform coverage . . . high degree of resistance to both fresh and salt water.

Although not a baking varnish and not intended for coil impregnation, #238 has many baking varnish properties.

To gain all these qualities of #238, it is only necessary to air-dry this material 6 hours, against 8 or more hours required by similar varnishes of this type.

MAY WE SUGGEST you send for a small sample on your Company letterhead, so that you may conclusively prove the merits of #238 Black Air Drying Varnish. This entails no obligation on your part.

Insulating Dolph's Varnish Specialists

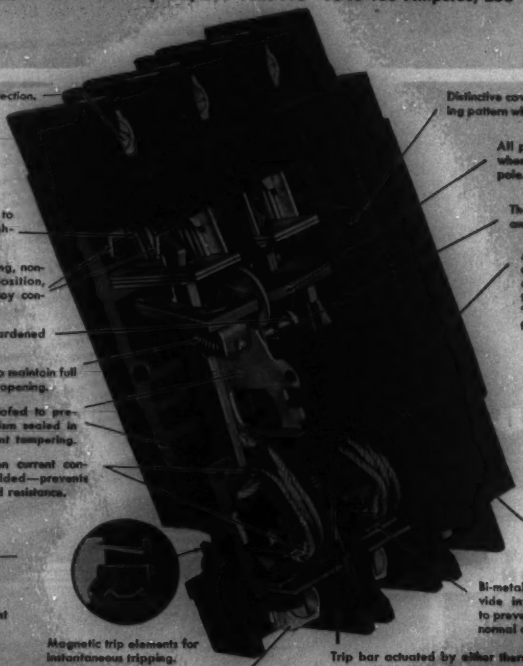
JOHN C. DOLPH COMPANY

1060 BROAD STREET · NEWARK 2, N. J

A New and Improved

100-AMPERE FRAME CIRCUIT BREAKER

Type ML2 • 15 to 100 Amperes, 600 Volts AC—50 to 100 Amperes, 250 Volts AC-DC



Designed for front connection.

Distinctive cover design provides pleasing pattern when breakers are grouped.

All poles trip simultaneously when overload occurs on any pole.

The mechanism is quick-make and quick-break.

Automatic tripping is clearly indicated; handle assumes intermediate position between "ON" and "OFF" when breaker is tripped by overload.

Arc chambers designed to provide effective, high-speed interruption.

Contacts are non-welding, non-oxidizing silver composition, mounted on copper alloy contact arm and terminal.

Bearing surfaces are hardened to reduce wear.

Springs cause contacts to maintain full pressure until instant of opening.

All steel parts rust-proofed to prevent corrosion; mechanism sealed in bakelite case to prevent tampering.

All connections between current connecting parts are welded—prevents loosening and increased resistance.

Breaker Unit
Dimensions
2 9/16" long
4 15/32" wide
3 3/4" high
4 7/8" maximum height including handle

Strong bakelite handle moves in sealed grooves.

Bi-metal overcurrent elements provide inverse time characteristic to prevent tripping on momentary normal overloads.

Magnetic trip elements for instantaneous tripping.

Trip bar actuated by either thermal or magnetic trip elements. Mechanism always trip-free, so contact cannot be held closed against short circuits or abnormal overloads.

Solder-Solderless connectors furnished on ratings of 35 to 100 amperes. Screw and eared washer 15-20-25 amperes.

• The new ML2 is furnished in distribution panelboards, as well as the three types of enclosures shown at right. Write for ML2 Bulletin, which gives complete details.

Weather-Proof and Dust-Tight

Explosion Resisting

Dust Resisting

SQUARE D COMPANY

DETROIT • MILWAUKEE • LOS ANGELES

New-Type Self-Supporting

NOW BUTTONS U-S-S Amerprene Cable runs right through trees. Overhead tree-trimming is eliminated. The line is easy to install, better looking, permits fewer interruptions to service and needs far less by required maintenance and repairs.
CONSTRUCTION DETAILS
1. Heavy galvanized steel messenger with copper wires inserted for conductivity.
2. Copper conductors.
3. High dielectric strength insulation.
4. Amerprene conducting cover similar to tire-tread rubber.
Note the simplicity of this construction and the elimination of metal pipes or crossarms. Insulation is easy, neater and cuts can be made quickly and easily.
1
2
3
4

EASY INSTALLATION...

1. POLE HANGER clamps steel messenger cable eliminating the strain on conductors. No crossarms or insulators needed.

2. SPLICE. Steel messenger is clamped as shown. All three conductors are then bound to messenger with heavy marlin. Each conductor can then be easily spliced.

3. TERMINATION. Messenger is clamped as shown and conductors can be terminated in transformer or pothead or run directly to a tap bracket.

U·S·S Amerprene *Self Supporting*

Amerprene Aerial Cables

PROVIDE BETTER CONTINUITY OF SERVICE THROUGH HEAVY TREES

at low cost!

THE PROBLEM of maintaining continuity of electric service through heavily wooded areas has been difficult, but the new U·S·S Amerprene Self-Supporting Aerial Cable promises an economical solution. Many types of aerial cable, some self-supporting, have been tried in the past but most of them had certain disadvantages which have been overcome in this design.

Look at the simplicity of the U·S·S Aerial Cable—three conductors wound around a strong steel messenger. The cable is balanced in construction—requires no troublesome straps or rings.

With this cable you can practically eliminate tree troubles and the high cost of tree trimming. Unsightly wire congestion in residential areas can soon be a thing of the past and you will not have to resort to the more expensive underground cable.

One big question was how to obtain maximum protection against normal static discharges and lightning and switching surges which might run much higher than normal operating voltage. Comprehensive tests showed that Amerprene conducting rubber covers promised better operating results than non-shielded cable. (Safe methods of splicing and terminating conductors were devised so that the line can be worked "hot" if necessary.)

The installation of these self-supporting cables is economically sound. You can use shorter, less costly poles. Crossarms and insulators are unnecessary except at a few points, and there is less danger of line breaks because of the added strength of the heavy steel messenger cable. Conducting Neoprene jackets are highly resistant to tree abrasion, will give long service life, provide ultimate safety and facilitate fault location.

Ask any American Steel & Wire Company representative for details of U·S·S Aerial Cable or write to any of the companies listed below.

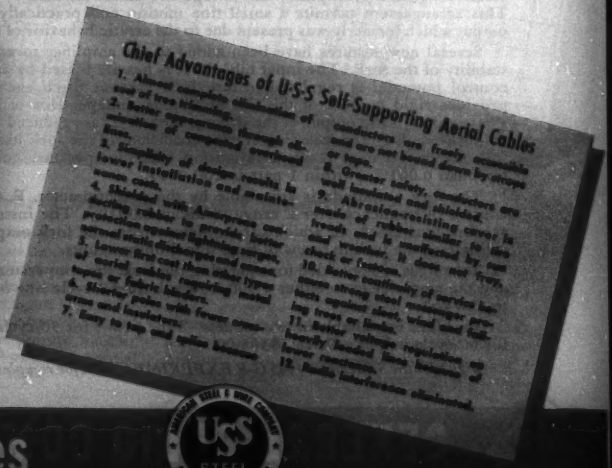
American Steel & Wire Company

Cleveland, Chicago & New York

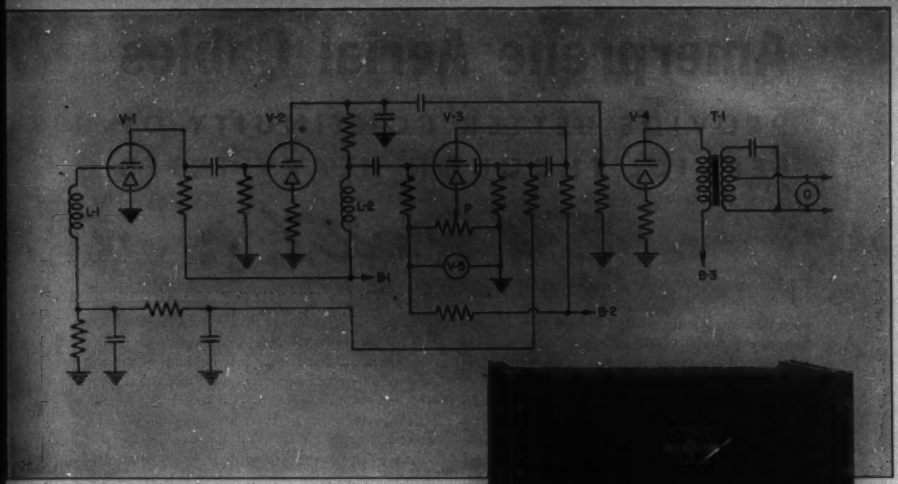
Columbia Steel Company, San Francisco, *Pacific Coast Distributors*
United States Steel Export Company, New York

UNITED STATES STEEL

4. RIGHT ANGLE BEND. Steel messenger is placed around ordinary angle fitting and conductors are bound with heavy marlin. Messenger takes the strain.


Chief Advantages of U·S·S Self-Supporting Aerial Cables
1. Almost complete elimination of cost of tree trimming.
2. Better appearance through elimination of congested overhead lines.
3. Simplicity of design results in lower installation and maintenance costs.
4. Shielded with Amerprene conducting rubber to provide better protection against lightning surges, normal static discharges and moisture.
5. Lowest first cost than other types of aerial cables requiring messenger or fabric binders.
6. Standard poles with fewer crossarms and insulators.
7. Easy to tap and splice between conductors are freely accessible and are not bound down by straps or tape.
8. Greater safety, conductors are well insulated and shielded.
9. Abrasion-resisting cover is made of rubber similar to tire treads and is unaffected by sun and weather. It does not rot, crack or fracture.
10. Better continuity of service between strong steel messenger permits operation about, wind and rain.
11. Better voltage regulation on heavily loaded lines because of lower resistance.
12. Radio interference eliminated.

Aerial Cables



NEW TUNING FORK
Accurate To 0.001 Per Cent

● This new vacuum-tube-driven precision fork, now available for non-military use, was developed as an improvement to our Type 815-A Precision Fork with microphone drive. One of the limitations to the stability of the microphone-driven fork was the random variations in the granular carbon in the microphone buttons. The fork itself, with a value of Q of about 19,000, was capable of considerably greater precision than the microphone drive would allow.

In the new fork, which is temperature-controlled, the microphone buttons have been replaced by a system which generates from the tine motion a small emf in the polarized electromagnet, L-1, amplifies this voltage and drives the fork by the second magnet, L-2. This arrangement permits a small tine motion and practically eliminates variation in output which formerly was present due to the erratic behavior of the microphone buttons.

Several new features have been added to the amplifier to contribute to the ultimate stability of the fork. The input tube, V-1, is heavily biased by an a-v-c tube, V-3, whose control potential is regulated in turn by a gaseous discharge tube, V-5. This system provides rigid control of the tine amplitude, independent of supply line fluctuations. Phase shifts in the output of the driving tube, V-2, are reduced to a very low minimum. With the high Q and low temperature coefficient of the fork itself, the result is a tuning fork standard whose residual variations, when temperature control is used, aggregate less than 0.001% *(within 1 part in 100,000)*.

The fork amplitude is adjustable by the potentiometer, P, permitting an electrical control of frequency over a range of about 0.001%. The instrument panel contains a synchronous clock, C, which can be driven from the fork output and can be used for calibrating the fork in terms of time-signal observations.

Terminals are provided for operating the fork, the temperature-control heater circuits and the amplifier from either a 100–130 volt 50–60 cycle line or from a d-c line of 100 to 130 volts.

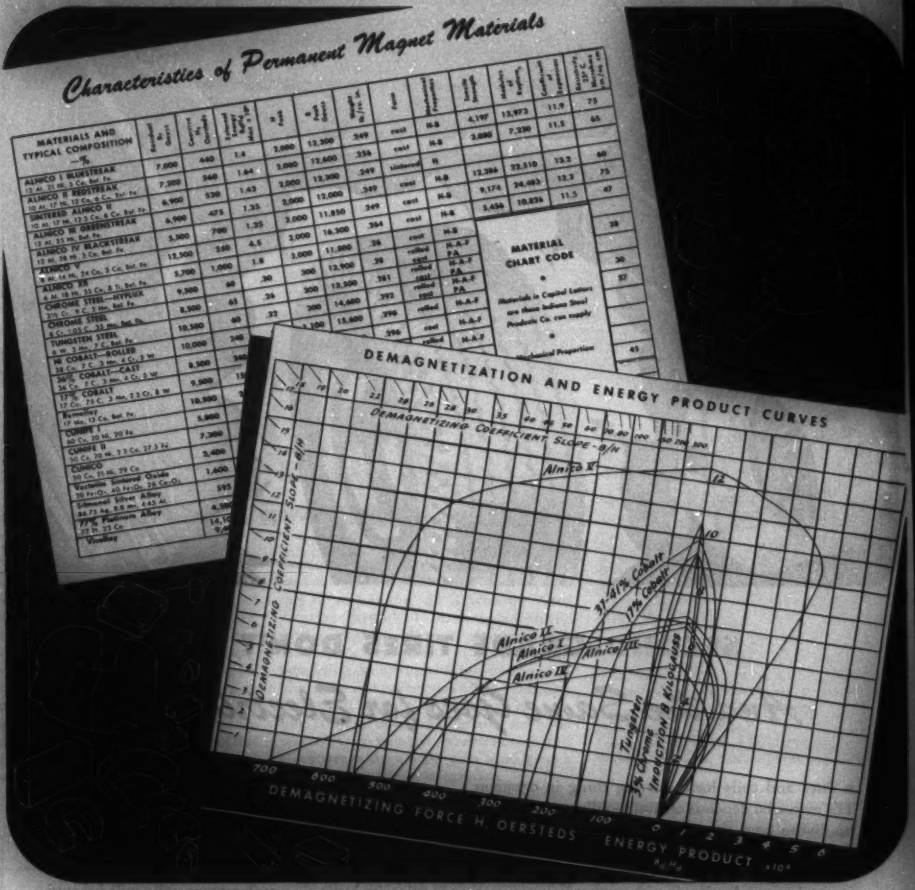
This fork is available in two models: Type 816-A for 50-cycle output and Type 816-B for 60-cycle output. Price: $385.00.

Write for the September, 1945 G-R EXPERIMENTER for complete Data and Specifications.

GENERAL RADIO COMPANY Cambridge 39, Massachusetts

90 West St., New York 6 920 S. Michigan Ave., Chicago 5 1000 N. Seward St., Los Angeles 38

PERMANENT MAGNETS MAY DO IT BETTE



Reference Charts on Permanent Magnet Materials

Engineers! Product designers! For your convenience, in handy reference form, we have prepared two charts (shown in reduced size above) giving helpful data on the energy product and physical characteristics of permanent magnet materials. A supply of these, printed on durable ledger stock, 11″ x 16″, is available for prompt mailing to any firm or individual considering commercial applications of permanent magnets.

Write for your free copy today.

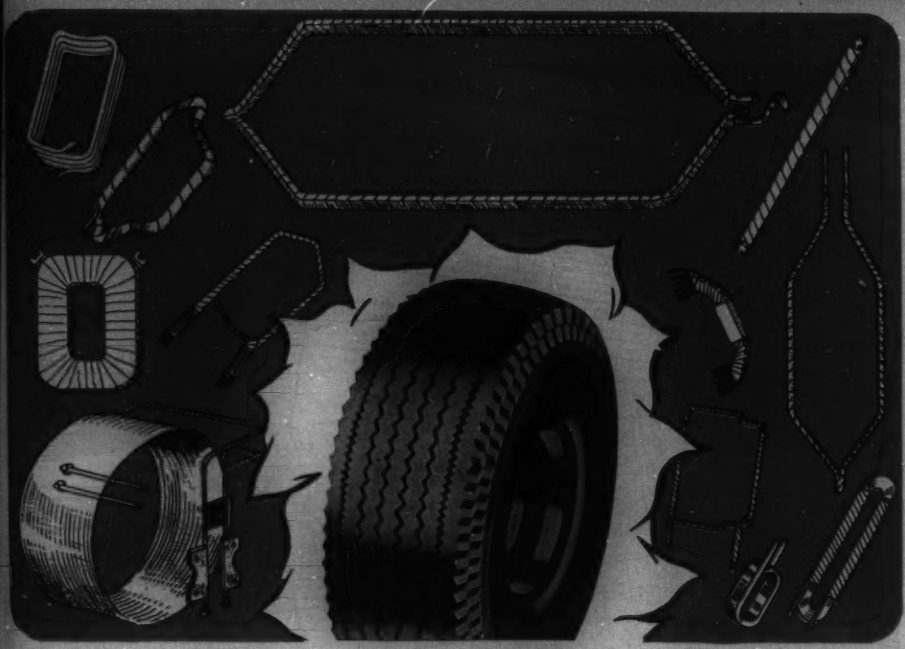
Our research and engineering specialists are at your service for consultation. Complete information on the facilities of The Indiana Steel Products Company—world's largest manufacturer of permanent magnets—is presented in our technical handbook, entitled "Permanent Magnet Manual," now on the press. We will be glad to send you a copy without charge.

★ ★ ★ **THE INDIANA STEEL PRODUCTS COMPANY** ★ ★ ★

6 NORTH MICHIGAN AVENUE, CHICAGO, 2 ILLINOIS

Copr. 1945, The Indiana Steel Products Co.

SPECIALISTS IN PERMANENT MAGNETS SINCE 1910



SECOND-GRADE TIRES DON'T PAY . . .

And the Same Goes for Electric Coils

• Tires and coils have one big thing in common. The man who depends on automobile travel to make his living buys the best tires he can find . . . the operation which depends on electric power needs the best coils which can be had. Premature failure means lost production in either case.

Four-ply tires are standard on new passenger cars. But the hard-riding salesman puts six-plies, or "deluxe" four-plies, on his car. He wants no tire trouble; he wants to reach that appointment on time. Do you?

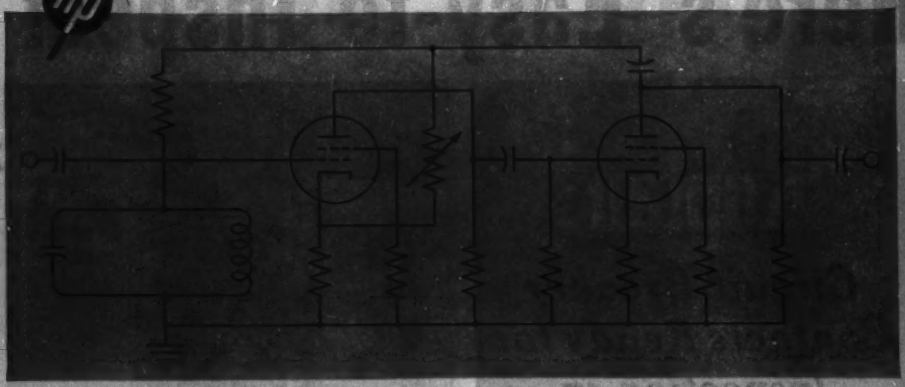
National coils "get you there on time." When standard construction can do the job, we furnish the best. But no rigid production-line technique cripples our ability to design and build special coils to overcome the causes of persistent, recurring coil trouble. When your electrical unit fails, call in National . . . the failure will be analyzed to determine its cause . . . replacement coils will be engineered to give you the longest possible coil life under the conditions imposed. If your conventional winding is merely changed to Mica-Glas or your old winding is completely modernized, it is because the change will benefit you in lower operating and maintenance costs.

Call in National. It will pay you.

NATIONAL ELECTRIC COIL COMPANY

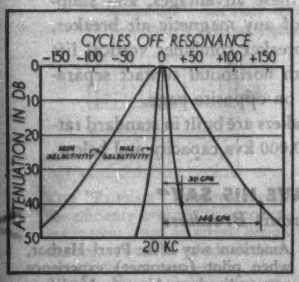
COLUMBUS 16, OHIO, U. S. A.

LABORATORY INSTRUMENTS FOR SPEED AND ACCURACY



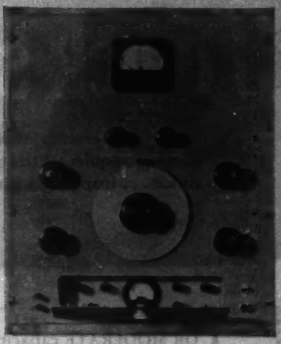
The High—and Variable "Q" of This Circuit Means Rapid, Accurate Wave Analysis

This *-hp-* Harmonic Wave Analyzer measures the individual components of complex waves with speed and surety, because of the highly efficient composite circuit shown above. The variable selectivity of the amplifier is the factor which makes it especially useful for measurements at higher frequencies. Regeneration is used to give the amplifier a high effective "Q," and a degeneration control provides variable selectivity. The resulting performance of this circuit is shown in accompanying graph.



In practical terms, variable selectivity means no tedious "searching out" of the harmonics to be measured. Yet the finger-tip control is easy to manage. This characteristic makes the *-hp-* Harmonic Wave Analyzer useful for many applications where constant selectivity would be unsuitable. Variable selectivity is required in measuring distortion of sound on recorded film, disks and other cases where there may be a small amount of frequency modulation. It is also used in integrating the noise spectrum in acoustic measurements and elsewhere when a wider pass band gives a more representative integration.

The *-hp-* Harmonic Wave Analyzer covers the audio spectrum from 30 to 16,000 cps. There is likewise a wide voltage range; full scale voltmeter readings may be obtained with inputs of .001 to 500 volts. Thus the 300A may be used with equal success with low output recording devices and high power modulating amplifiers. Other features which make it unexcelled for both laboratory and production testing are the linear meter scale, fully protected against overloads, and the built-in calibrating system to standardize voltage measurements. With the stability, accuracy, flexibility and ease of operation of the Harmonic Wave Analyzer, Hewlett-Packard continues to set a new standard. 1119



These -hp- Representatives Are at Your Service

Eastern Representative:
Burlingame Associates, Ltd.
11 Park Place
New York 7, N. Y.—Worth 2-2171

Midwestern Representative:
Alfred Crossley
549 West Randolph Street
Chicago 6, Illinois—State 7444

Western Representative:
Norman B. Neely Enterprises
7422 Melrose Avenue
Hollywood 46, California—Whitney 1147

Canadian Representative:
Atlas Radio Corporation
560 King Street West
Toronto 2, Canada—Wa 4761

HEWLETT-PACKARD COMPANY

BOX 1119 • STATION A • PALO ALTO, CALIFORNIA

Audio Frequency Oscillators *Signal Generators* *Vacuum Tube Voltmeters*
Noise and Distortion Analyzers *Wave Analyzers* *Frequency Meters*
Square Wave Generators *Frequency Standards* *Attenuators* *Electronic Tachometers*

Here's Easy-to-Inspect

"Ruptair"

Circuit Breaker Contacts Ready for Inspection in

3 quick steps

NOTE: Inherently, this allmetal breaker requires little maintenance . . . inspection is routine.

1 LOWER BREAKER

Photo shows "Ruptair" magnetic air circuit breaker in normal operating position (at right) and in the lowered disconnect position. The breaker is quickly and easily lowered with a manually or electrically operated crank-hoist.

FOR MODERATE capacity installations, 5 kv and below, the "Ruptair" magnetic air breaker is increasingly popular among operators. Because oil is eliminated from the breaker, fire hazard is reduced, and maintenance requirements are much less . . . particularly for repetitive operation.

In addition to these advantages, and simplest inspection of any magnetic air breaker, the "Ruptair" breaker combines vertical lift construction with horizontal contact separation, illustrated on opposite page.

"Ruptair" breakers are built in standard ratings of 5 kv, 150,000 kva capacity and below.

ALLIS-CHALMERS LETS THE CUSTOMER "HAVE HIS SAY"

You Can Choose From 3 Basic Types of Circuit Breakers

☛Allis-Chalmers wholeheartedly endorses the principle of standardization, wherever the interests of customers are best served. Actually, A-C *introduced* standard metalclad switchgear units to U. S. industry.

☛What Allis-Chalmers has *not* yet done is to limit *types* of circuit interrupters available in switchgear units. For our A-C engineers believe that the customer rightfully plays an essential part in the development of industrial equipment.

☛Take military aircraft as a parallel case to switchgear. A problem never really solved by the "efficient" German Luftwaffe—that of preparing planes for combat under current combat conditions — was licked by the U. S. Air Forces in a typically American way after Pearl Harbor, when pilot (customer) experience was utilized at Aircraft Modification Centers.

☛In the same way, by offering oil, magnetic air, and air blast breakers for buyer choice, A-C lets the customer "call his own tune" . . . cooperate in the *evolution* of tomorrow's circuit breaker.

Magnetic Air Breaker

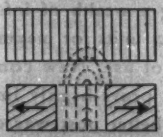
2 WITHDRAW IT

In the disconnect position, the "Ruptair" breaker can be placed on a transfer truck, and pulled out into the aisle. For safety, shutters used to isolate primary disconnect contacts are automatic in their operation.

3 REMOVE SIDE PLATES

Finally, light-weight insulating barriers are removed, each barrier being held in place by two cap-screws. Since the "Ruptair" arc chute is above the contact structure, it need not be disturbed for contact inspection.

"Ruptair" Circuit Breaker Is Engineered For Maximum Interrupting Efficiency

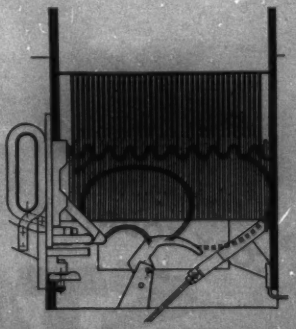


THE "RUPTAIR" breaker depends for efficiency over entire interrupting current range on several design factors . . . one of which is horizontal contact separation.

Since arcing contacts part in the horizontal direction, the arc is assisted into the arc chute by natural thermal effect — no complex interrupting structure is required! In addition, position of arc chute *above* contacts makes it possible to inspect the contacts without removing the chute.

By the coordination of contacts and arc runners, shown in the accompanying diagram, the arc is quickly and easily transferred from the horn-shaped moving contact to the stationary arc runner, opposite.

Another unique feature is the intermediate stationary contact which fully connects the magnetic blowout coil into the circuit before actual contact separation . . . results in augmented blowout effect.



ALLIS CHALMERS

Milwaukee Wisconsin

TACT DATA

... just off the press!

If your product uses contacts you'll find in this new Stackpole Contact Catalog a wealth of information designed to help you select units for maximum service under all conditions of use. New contact developments described will prove highly important in the design of smaller, better post-war electrical equipment. Write today!

STACKPOLE CARBON COMPANY, ST. MARYS, PA.

WRITE FOR YOUR COPY TODAY!

STACKPOLE

BRUSHES and CONTACTS (All carbon, graphite, metal and composition types) RARE METAL CONTACTS • IRON CORES • WELDING CARBON PRODUCTS PACKING, PISTON AND SEAL RINGS • RHEOSTAT PLATES AND DISCS BATTERY CARBONS • POWER TUBE ANODES • CARBON PIPE, ETC.

Navy Reveals "Top Secret"

AWARDS SPECIAL NAVAL ORDNANCE "E" WITH 3 STARS TO IRC FOR "A WAR TIME TASK OF FIRST MAGNITUDE."

And IRC, with pride tempered by humility, records its gratitude for the privilege of making a modest contribution to Victory..and Peace.

The story of the Navy's "Project A" . . . the VT-Fuze, rates a close second in ordnance drama to the mighty Atomic Bomb. This tiny radio sending and receiving set hardly larger than a fist, fitted into the nose of a projectile or bomb, emits impulses at the speed of light itself. As the missile nears its objective the proximity device automatically detonates the charge and showers the target. . . . "Top secret" during its many months of development and use, the VT made possible an effective defense against Nazi Buzz Bombs and the Jap Kamikazes and greatly increased the accuracy of artillery fire. . . . ***IRC is honored to have been designated as the sole design and production source for the accurate and rugged BTR Resistors required—a total of 306,359,511!..*** Our sincere thanks are due to the Navy Department Bureau of Ordnance, Eastman Kodak Company, McQuay-Norris Manufacturing Co., Sylvania Electric Products, Inc., the Crosley Corporation and the Radio Corporation of America for the splendid cooperation which they extended to us throughout the entire period of design, development and production of the joint project. . . . United toward a common goal, their efforts and those of the eighty thousand men and women workers who participated, symbolize the strength that is America!

International Resistance Co.

401 N. Broad Street — Philadelphia 8, Pa.

In Canada: International Resistance Co., Ltd., 11 King St., W., Toronto

IRC — PREFERRED FOR PERFORMANCE — FIXED & VARIABLE RESISTORS

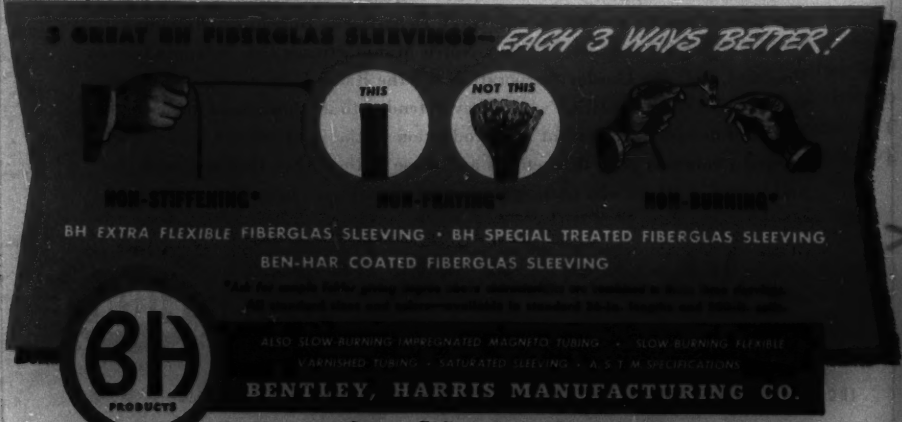
IRC Makes More Types of Resistance Units, in More Shapes, for More Applications Than Any Other Manufacturer in the World.

YOU CAN'T KEEP A
COLD CUSTOMER SOLD!
BH SPECIAL TREATED FIBERGLAS SLEEVING
Tops in Electric Heaters!
• Won't Fray When Cut
• Flexible and Strong
• Non-Burning to 1200°F

WHETHER he's Mr. Big of Industry or plain Mr. Homebody, the performance of your product's electrical insulation can make or break *his* good will, influence *your* future sales. Look at *all* the hazards of faulty or insufficient insulation. See why hundreds of manufacturers are protecting *their* products with BH Fiberglas Sleeving—the insulation that's way ahead in every important requirement, thanks to the *exclusive* BH process.

BH Fiberglas Sleeving is *permanently* flexible and non-fraying, the *original* sleeving to combine these qualities with heat resistance to 1200°F., with high tensile strength, and with resistance to moisture, oil, grease and most chemicals. It's easier to handle and install, and lasts longer in severest service. That's why BH Special Treated Fiberglas Sleeving, for instance, does a trouble-free job when the heat's on—why Mr. Room Heater Customer is sold *for good* when the heater's BH-equipped.

Whatever your product may be, if it depends on electrical insulation, you can count on one of the three BH Fiberglas Sleevings to meet your strictest needs. Send for free BH samples *today* —test them yourself—expect surprising results!


3 GREAT BH FIBERGLAS SLEEVINGS—EACH 3 WAYS BETTER!
THIS
NOT THIS
NON-STIFFENING*
NON-FRAYING*
NON-BURNING*
BH EXTRA FLEXIBLE FIBERGLAS SLEEVING • BH SPECIAL TREATED FIBERGLAS SLEEVING
BEN-HAR COATED FIBERGLAS SLEEVING
ALSO SLOW BURNING IMPREGNATED MAGNETO TUBING • SLOW BURNING FLEXIBLE VARNISHED TUBING • SATURATED SLEEVING • A.S.T.M. SPECIFICATIONS
BH PRODUCTS
BENTLEY, HARRIS MANUFACTURING CO.
Dept. C Conshohocken, Penna.

No Electrical Equipment Made Can Be Any Better Than Its Insulation

NOW AVAILABLE!

As one of the world's largest and most experienced producers of insulating varnishes, General Electric supplied millions of gallons during the war.

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These varnishes helped protect vital electrical components in our fighting equipment . . . helped keep electrical equipment on the job for steady war production.

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G-E Insulating Varnishes met—often exceeded—exacting military and naval needs. This was made possible by General Electric's 45 years' experience in insulating varnish research and manufacture . . . and meticulous adherence to rigid General Electric Quality Control precepts.

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Now G. E.'s huge varnish production capacity—plus expert technical service—is available to peace industry.

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For full details consult your local General Electric Merchandise Distributor or write direct to Section RIMA-1159, Resins and Insulating Materials Division, Chemical Department, General Electric Company, Schenectady 5, New York.

GENERAL ELECTRIC

G-E INSULATING VARNISHES

G. E. Offers a Complete Line of Insulating Materials

What kind of Fiberglas* laminate would you use?

Fiberglas-base laminates are made with many different kinds of resins—to meet a wide range of electrical and mechanical requirements. The finished materials may be obtained in sheet form, in rods or tubes, or may be molded or shaped to special forms.

Laminates with *Fiberglas Cloth* as a base are used in large volume for motor and generator applications. Their temperature limits and moisture resistance vary with the type of resin used. They have high dielectric strength.

Where minimum space and high strength are required, Fiberglas-base laminates are usually used. Typical applications are aircraft generators, dynamotors, etc.

Laminates with *Fiberglas Mat* as a base are used primarily by radio and electronics industries. The Fiberglas Mat in combination with resins provides dimensional stability, moisture resistance, temperature resistance and adequate mechanical strength for high-frequency, low-electrical-loss parts.

Most manufacturers of electrical laminates make one or more types of Fiberglas-base products.

Complete Information

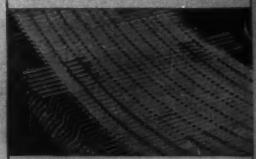
The new Fiberglas catalog EL 44-7 gives performance and application data of importance to anyone concerned with electrical insulation. It contains facts about each of the many types of Fiberglas-base materials which are providing better, "High Safety Factor" insulation. Write for your copy today. *Owens-Corning Fiberglas Corporation, 1859 Nicholas Building, Toledo 1, Ohio.*

In Canada, Fiberglas Canada Ltd., Oshawa, Ontario.

Each distributor of Fiberglas-base Insulation Materials has his own source of supply, since Owens-Corning Fiberglas Corporation does not process these materials.

There is a **FIBERGLAS** Insulation Material for every need

Sheets, tubes and rods of Fiberglas-base plastics are made by many plastics producers.



In sheet form Fiberglas laminates are made in thicknesses from 1/32" to 3/16". Greater thicknesses are used for panel and switchboard material.

Fiberglas Cloth is used with Melamine to produce this circuit breaker panelboard. Has astounding impact strength and exceptional electrical characteristics.

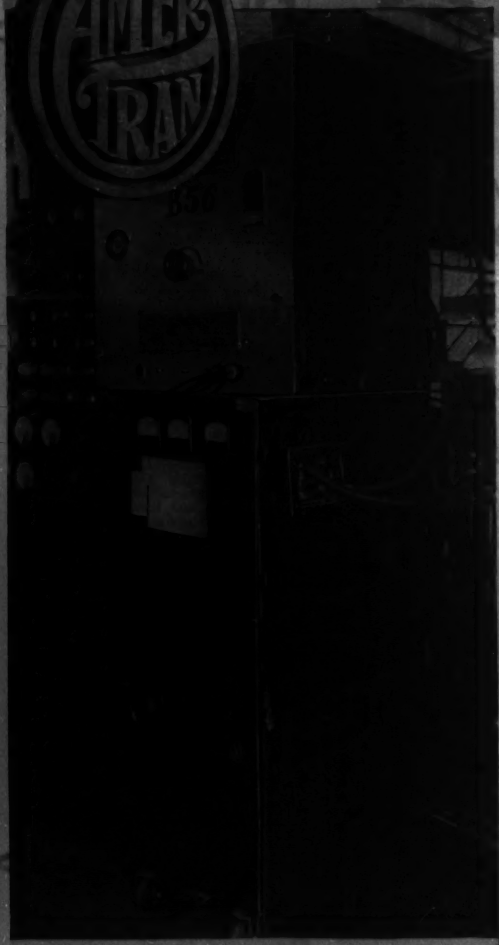
Write for catalog EL 44-7, today.

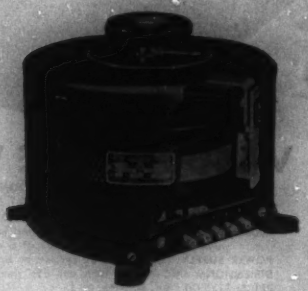
FIBERGLAS

*T. M. Reg. U. S. Pat. Off.

ELECTRICAL INSULATION MATERIALS

TRANSTATS ARE THE "TRIGGERS" OF TUNG-SOL'S BOMBARDERS





Transtat for 0.3 to 20 KVA.

Whenever heavy alternating currents are controlled at the Tung-Sol Lamp Works, Transtats are put on the job. Tung-Sol builds quality into tubes with the help of Transtats used for Life Testing, Aging and Induction Heating.

To provide the unusual ruggedness and close control needed for this work, the Transtat Commutator is ground out of the periphery of the coil—where the wires are flat and parallel. This produces a glass-smooth, broad brush track. It permits a longer, cooler running brush, prevents arcing and jumping and provides practically stepless control. A transformer-type regulator, the Transtat will not distort wave form, interfere with radio reception or disturb power factor. State rating required when writing for bulletin.

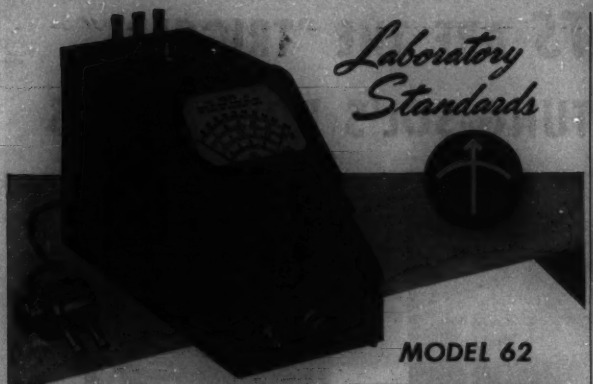
Shown here are Bombarder (below with black panel) and Induction Heater (above with light panel) at Tung-Sol, Newark, N. J., Plant.

AMERTRAN

Pioneer Manufacturers of Transformers, Reactors and Rectifiers for Electronics and Power Transmission

AMERICAN TRANSFORMER COMPANY

178 Emmet Street Newark 5, N. J.



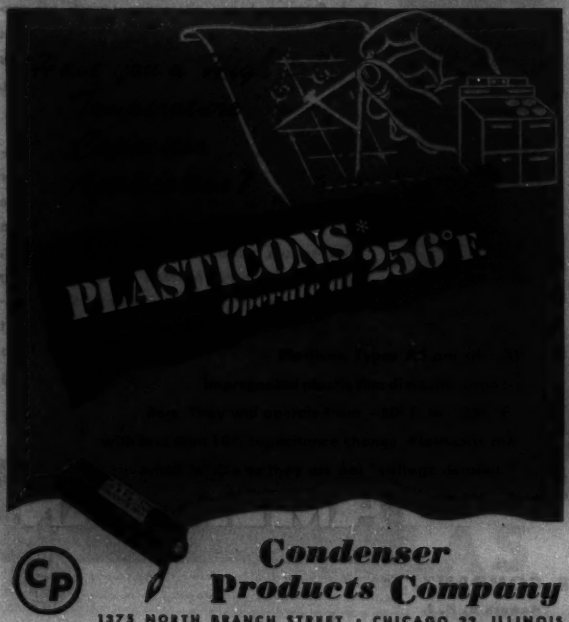
MODEL 62

VACUUM TUBE VOLTMETER

SPECIFICATIONS:

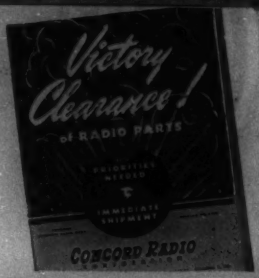
RANGE: Push button selection of five ranges—1, 3, 10, 30 and 100 volts a. c. or d. c.
ACCURACY: 2% of full scale. Useable from 50 cycles to 150 megacycles.
INDICATION: Linear for d. c. and calibrated to indicate r.m.s. values of a sine-wave or 71% of the peak value of a complex wave on a. c.
POWER SUPPLY: 115 volts, 40-60 cycles—no batteries.
DIMENSIONS: 4¾" wide, 6" high, and 8½" deep. **WEIGHT:** Approximately 6 lbs.
PRICE: $135.00 f.o.b. Boonton, N. J. Immediate Delivery

MEASUREMENTS CORPORATION
BOONTON, NEW JERSEY



Condenser Products Company
1375 NORTH BRANCH STREET • CHICAGO 22, ILLINOIS

RADIO PARTS ELECTRONIC EQUIPMENT



FREE! CONCORD Victory Clearance Flyer

Ready now! 32 Bargain-packed pages listing thousands of standard-make, top-quality radio parts and electronic supplies—now available without priority at low VICTORY CLEARANCE prices. The values listed below are typical of the important savings offered in Meters, Condensers, Transformers, Resistors, Controls, Switches, Relays, Test Equipment, Generators, Microphones, Tools, and hundreds of Repair, Replacement, and Accessory Parts.

D.C. Milliammeters

2½" flange mtg. type. Metal case dull black finish. G.E. 0-300 M.A. C10650 Specially Priced, $4.95

Output Transformer

Hermetically sealed. Six studs, 1, 2, and 3 are pri. 4, 5, and 6 the sec. Pri. ind. at 5 V. 1000 cy.: .20 H. Ratio sec. to pri. 3.02:1. Size: 3¼ x 2 41/64" 529045 Your cost, $1.95

Immediate Shipment from CHICAGO or ATLANTA

Huge stocks in *two* convenient warehouses—one in CHICAGO and one in ATLANTA—are ready to supply you quickly with needed parts of dependable nationally-known quality—and at VICTORY CLEARANCE prices that mean real savings. Mail the coupon below NOW for your FREE copy of CONCORD'S VICTORY CLEARANCE Flyer.

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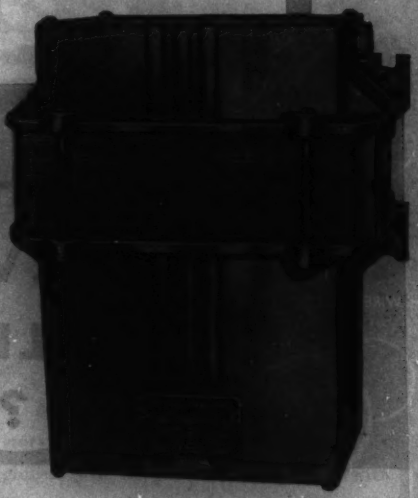
Parts to Radio Corporation
CHICAGO 7, ILL. ATLANTA 3, GA.

CONCORD RADIO CORPORATION
901 W. Jackson Blvd.
Dept. C-115, Chicago 7, Ill.
Please RUSH FREE copy of CONCORD'S new 32 page VICTORY CLEARANCE Flyer.
Name.....
Address.....
City..... State.....

RAYTHEON VOLTAGE STABILIZERS



ENDBELL MODEL

★ **CONTROL OF OUTPUT VOLTAGE** to within ±½% of 115 V. or 230 V. This assures accurate operation of electrical equipment by stabilizing A.C. voltage from supply mains where input often varies as much as from 95 to 130 V. or from 190 to 260 V.

★ **QUICK RESPONSE.** Stabilizes varying input voltage within one twentieth of a second. Output variations cannot be detected on an ordinary voltmeter.

★ **STABILIZES** at any load within rated capacities from 95-130 V. and 190-260 V.

★ **ENTIRELY AUTOMATIC.** No adjustments. No moving parts. No maintenance. A magnetic unit assuring long, service-proof life.

★ **RAYTHEON VOLTAGE STABILIZERS** are improving performance of electrical equipment in a wide variety of applications.

★ **YOU'LL FIND** the complete story in Stabilizer Bulletin DL48-537. Write for your copy today.

ENDBELL MODEL—DIMENSIONS IN INCHES

Catalog Number	Cap'y in Watts	OVERALL			
		L		W	H
		50~	60~		
VR-5	500	13 1/4	12 1/2	9 5/8	8 1/2
VR-6	1000	14 3/4	14	14 3/4	11 7/8
VR-7	2000	17 1/2	16 3/8	14 3/4	11 7/8

CASED MODEL

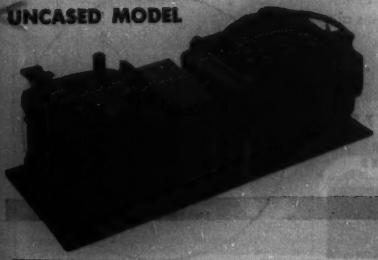
CASED MODEL
DIMENSIONS IN INCHES

Catalog Number	Cap'y in Watts	OVERALL		
		L	W	H
VR-1	30	8 1/8	37/16	4 1/2
VR-2	60	11 5/8	5 1/8	5 5/8
VR-3	120	15	6	6 1/8
VR-4	250	18 5/8	7	8 1/8

APPLICATIONS:

Radio • Television
Communications • Radar
Motion Pictures
Sound Recording
Electronic Devices
Constant Speed Motors
Production Machinery
Signal Systems
X-ray Equipment
Testing and Laboratory Equipment

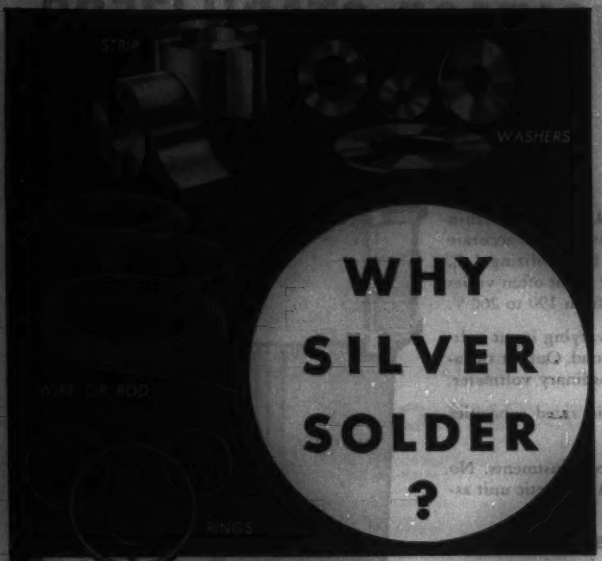
UNCASED MODEL



UNCASED MODEL
DIMENSIONS IN INCHES

Catalog Number	Cap'y in Watts	OVERALL		
		L	W	H Max.
VR-1	30	7 9/16	3	3 5/8
VR-2	60	7 7/8	5 11/16	5 2/16
VR-3	120	12 7/32	5 11/16	5 3/8
VR-4	250	13 9/16	6 3/4	7

RAYTHEON
MANUFACTURING COMPANY
WALTHAM 54, MASS.
ELECTRICAL EQUIPMENT DIVISION
Excellence in Electronics



Silver soldering, because of its speed, economy, and durability has replaced for many purposes former methods of soft soldering, high temperature brazing, welding, riveting or bolting. Cast and forged constructions, in many instances, have been replaced by the faster and less expensive method of fabricating two or more easily joined parts, soldering them together, then finishing to dimension.

Modern alloys and light gauge metals, likely to be damaged by high temperature brazing or welding, have been particularly aided by the use of low temperature, fast spreading silver solder. Likewise, the use of preformed rings or washers has materially speeded up straight line production.

In cooperation with industrial engineers, the D. E. Makepeace Company has developed a wide variety of precious metal solder alloys to meet practically every industrial requirement. These solders flow easily, penetrate deeply, and diffuse evenly. The joints so affected are stronger, in most instances, than the parts joined and the junction is durable, ductile, leak proof, corrosion resistant and high in electrical and thermal conductivity.

To help you with any problems which you may have, we maintain a fully equipped research and testing laboratory as well as a staff of thoroughly experienced metallurgists, chemists and consultants who will be pleased to assist you with any problem you may have to the full extent of their facilities and ability. Your inquiries are cordially invited.

START RIGHT with **Makepeace** PRODUCTS

SHEETS · WIRE · TUBING · SOLDERS
FABRICATED PARTS AND ASSEMBLIES

D. E. MAKEPEACE CO.

MAIN OFFICE AND PLANT — ATTLEBORO, MASSACHUSETTS
New York Office, 10 Church St. — Chicago Office, 55 East Washington St.

No Fallacious Guesses.

There is no guessing with a Matthews Teleheight. Any lineman can be taught to use it and get any height within an inch or so. He can learn in five minutes.

The extra cost of just one wrong guess will pay for one or two Matthews Teleheights. Hundreds of them are saving lots of money for their owners all over the country. Many are being used for quickly figuring the cubical contents of buildings, the clearance of bridges, highlines, etc.

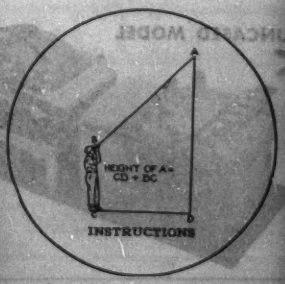
Matthews Teleheight is only five inches long. Has no moving parts. It is furnished with a leather carrying case that will fit in the vest pocket. The drawing below shows how simple are the directions for using it.

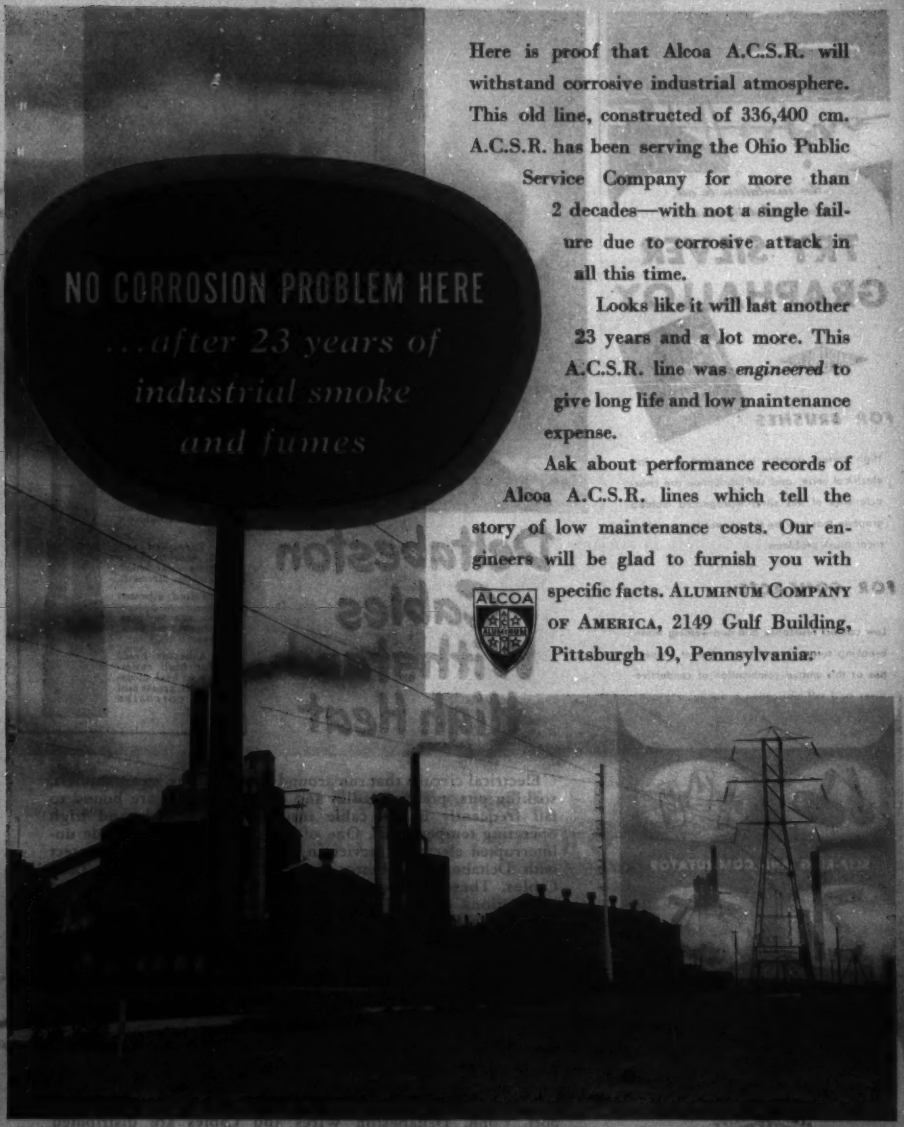
Great for Appraisal Jobs.

Try one at our risk of your approval.

W. N. MATTHEWS CORPORATION

ST. LOUIS, U. S. A.



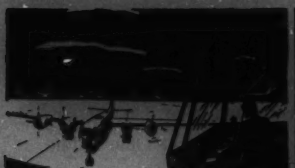


Here is proof that Alcoa A.C.S.R. will withstand corrosive industrial atmosphere. This old line, constructed of 336,400 cm. A.C.S.R. has been serving the Ohio Public Service Company for more than 2 decades—with not a single failure due to corrosive attack in all this time.

Looks like it will last another 23 years and a lot more. This A.C.S.R. line was *engineered* to give long life and low maintenance expense.

Ask about performance records of Alcoa A.C.S.R. lines which tell the story of low maintenance costs. Our engineers will be glad to furnish you with specific facts. ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh 19, Pennsylvania.

ALCOA A-C-S-R



An invitation to all electrical designers to

TRY SILVER GRAPHALLOY

FOR BRUSHES

High current density, low contact drop, low electrical noise, and self-lubrication are characteristics of this silver-impregnated molded graphite that may be the answer to your electrical brush problems.

FOR CONTACTS

Low contact resistance and non-welding when breaking surge currents are inherent properties of this unique combination of conductive silver and self-lubricating graphite.

SLIP-RING AND COMMUTATOR

BRUSHES AND CONTACTS

SAMPLES of Silver Graphalloy will be gladly furnished for test on your applications. Silver Graphalloy is usually silver plated to permit easy soldering to leaf springs or holders. Why not WRITE NOW for your test samples?

ALWAYS SPECIFY GRAPHALLOY

GRAPHITE METALLIZING CORPORATION

1053 NEPPERHAN AVE. • YONKERS, NEW YORK

Deltabeston Cables Withstand High Heat

Here's how we build trouble-free service in Deltabeston Apparatus Cable Type AVA.

1. Very soft, small copper strands—for greater flexibility and to withstand vibration.
2. Heatproof felted asbestos — for protection against overload conductor heat.
3. Varnished cambric—for moisture resistance and high dielectric strength.
4. Felted asbestos —for extra protection against high ambient temperatures.
5. Asbestos braid —for high resistance to heat, moisture, oil, grease and most corrosive vapors.

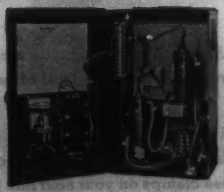
Electrical circuits that run around boiler rooms, steam tunnels, soaking pits, pouring ladles and other hot spots are bound to fail frequently unless cable insulations can withstand high operating temperatures. One of the safest ways to provide uninterrupted electrical service in these torrid zones is to protect with Deltabeston Asbestos-insulated Power and Motor Lead Cables. These heat-resistant cables have proved in countless installations that the asbestos-insulation just won't bake out despite constant, high heat.

If excessive heat is causing frequent power failures in your mill, investigate G-E Deltabeston Asbestos-insulated Cables now. Deltabeston is used extensively for power, lighting and control circuits especially where severe operating conditions prevail. General Electric manufactures a complete line of asbestos-insulated cables including many special designs. They're constructed not only to withstand excessive heat but high humidity, oil, grease and most corrosive vapors.

For additional information write to Section Y1155-32 Appliance and Merchandise Dept., General Electric Company, Bridgeport, Conn. Deltabeston Wires and Cables are distributed nationally by Graybar Electric Co., General Electric Supply Corp., and other G-E Merchandise Distributors.

GENERAL ELECTRIC

BY RESISTANCE FLASH WELDING WITH ELECTRONIC CONTROL



WESTINGHOUSE WELD-O-TROL is now being profitably applied to control resistance flash welding operations in scores of plants. Ignitron tubes, operating as electronic contactors, replace mechanical methods in making and breaking currents rapidly with no arc, no noise, no moving parts.

This case history is typical of the highly satisfactory results being obtained daily with electronic control on resistance flash welders.

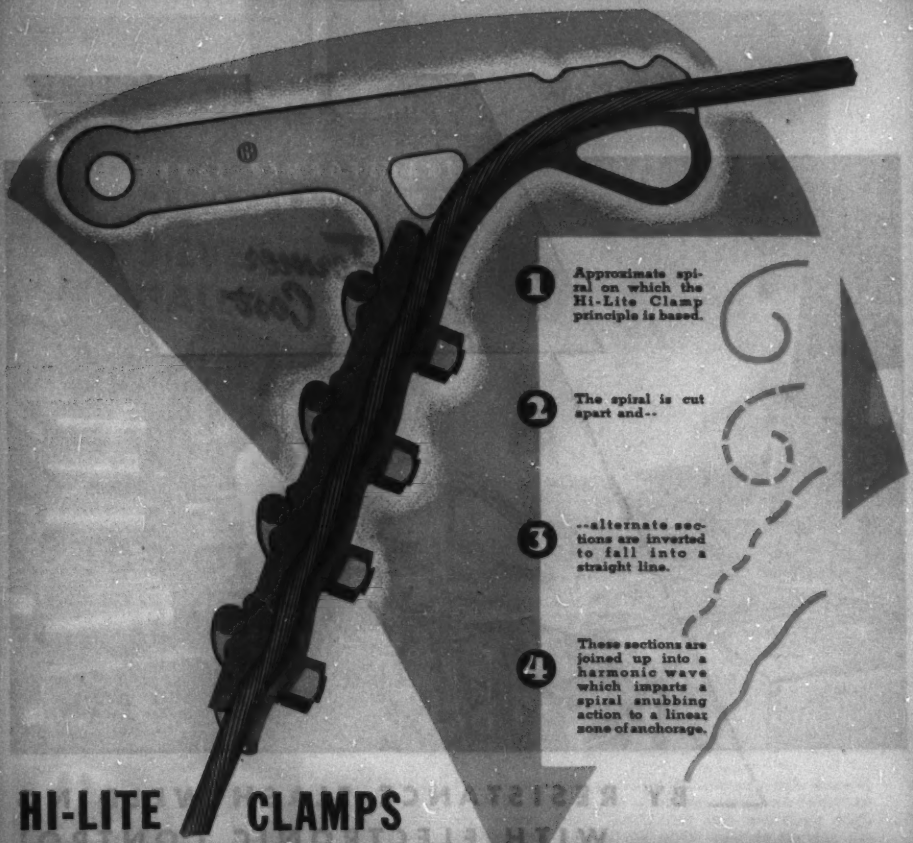
Finished manufacturing cost of these metal tanks was cut to 1/7th of the cost incurred by former methods of welding. This reduction was effected by the elimination of a fitting and tacking operation; also the elimination of a cleaning and grinding process which had been necessary to hold the welded tank to the close tolerances required.

To learn how electronic control can be profitably applied to *your* flash welding operations, contact your nearest Westinghouse office. Or write Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pa.

J-21365

Westinghouse

Electronics at Work


1
Approximate spiral on which the Hi-Lite Clamp principle is based.
2
The spiral is cut apart and--
3
--alternate sections are inverted to fall into a straight line.
4
These sections are joined up into a harmonic wave which imparts a spiral snubbing action to a linear zone of anchorage.

HI-LITE CLAMPS GET THE MOST OUT OF A SOUND PRINCIPLE

O-B HI-LITE CLAMPS have been compared to a vise with kid-glove jaws, because they grip the conductor with a hold that will develop the full strength of the cable, yet do it so gently that you can scarcely see where the clamp has been attached.

This is accomplished by utilizing a spiral snubbing action--one of the most efficient mechanical advantages known to physics. Because a spiral would be unhandy on a pole top, it has been developed into a harmonic wave; but it retains all of its original holding power. We have sketched how this is done.

The jaw or keeper piece of an O-B Hi-Lite Clamp does not act with the crushing force of a vise jaw, but rather performs like the hand that holds a rope snug to a snubbing drum. Hence, the lack of cable deformation.

There is a lot of sound design in an O-B Hi-Lite, just as there is a lot of satisfactory service and long conductor life. Specify these clamps on your next line job.

2810-H

Ohio Brass

MANSFIELD, OHIO

CANADIAN OHIO BRASS CO., LTD., NIAGARA FALLS, ONTARIO

RARIN' TO GO!

Conditioned by four hard fighting years, U.S. Wires and Cables are back in civilian gear.

Tough and reliable as they were at the start, they're even tougher and more reliable today.

The war experience proved the most valuable in all our wire-making history. Unpredictable developments in fighting methods demanded changes in almost every type of wire and cable.

Under the spur of necessity, U. S. Rubber Technicians met every challenge. The normal progress of many years was accomplished in a few.

The Electrical Industry is now offered a new and complete line. We are ready to serve the Public Utilities in the broad program they are launching, the Electrical Manufacturer already at work on new products, the Electrical Engineer facing new problems.

U. S. ELECTRICAL WIRES AND CABLES

Serving Through Science

Listen to "Science Looks Forward"—new series of talks by the great scientists of America—on the Philharmonic-Symphony Program. CBS network, Sunday afternoon, 3:00 to 4:30 E.S.T.

UNITED STATES RUBBER COMPANY

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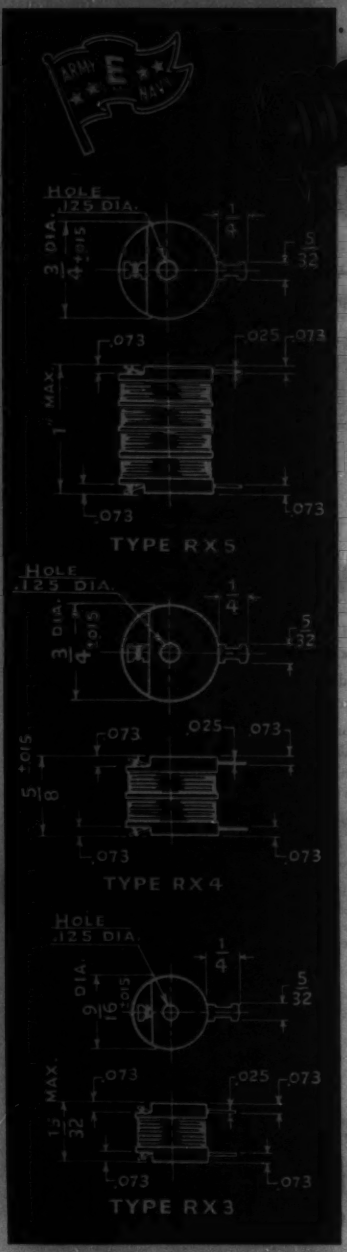


3 NEW BOBBIN TYPE RESISTORS

MAXIMUM RESISTANCE VALUES

Type RX3	Type RX4	Type RX5
100,000 ohms	300,000 ohms	500,000 ohms
(wound with 1.5 mil. dia. ceramic-insulated wire)		
25,000 ohms	75,000 ohms	125,000 ohms
(wound with 2.5 mil. dia. ceramic-insulated wire)		

MAX. POWER RATING AT 80° C. AMBIENT

1 watt — 2 watts — 3 watts

MAX. TEMPERATURE—Ambient plus rise: 150° C.

RESISTANCE TOLERANCE: ±½% to ±5%, as specified. Where close tolerances are necessary, power ratings should be reduced in order to maintain stability. For example, one-third power rating is consistent with 1% tolerance.

TEMPERATURE COEFFICIENT—Standard temperature coefficient is that of nickel-chromium wire, .017%. Lower coefficients can be provided with special alloy wires, restricting the resistance range in some cases.

STABILITY—Resistors can be current- and temperature-aged after winding to provide instrument resistor stability. When operated at ratings consistent with tolerance, stability is ±0.1% or 1/10 of tolerance, whichever is larger.

CONSTRUCTION—Resistors are wound with ceramic-insulated Sprague Koolohm resistance wire on molded, high-temperature plastic forms. The lug terminals are tinned copper inserts molded in the plastic form.

HUMIDITY RESISTANCE—Resistors are impregnated to provide protection against tropical humidity conditions.

SPRAGUE KOOLOHM

Trademark Reg. U. S. Pat. Off.

WIRE-WOUND RESISTORS

FIRST with Grade 1, Class 1 Resistors; FIRST with resistors wound with ceramic-insulated wire; FIRST with glass-to-metal sealed resistors; FIRST with glazed ceramic coatings and new style end seals; FIRST with Megomax high-resistance, high-voltage resistors.

SPRAGUE ELECTRIC COMPANY, Resistor Division, NORTH ADAMS, MASS.

MULTIPRESS SHAVES Production Costs for GILLETTE

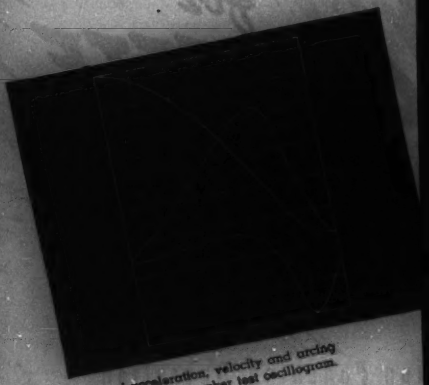
Higher Output on Precision Punching Operation

MULTIPRESS proves its advantages on another task . . . punching key slots in metal safety razor guards at the Gillette plant in South Boston. Performance records show reduced "downtime" for maintenance and tooling "setups" . . . thus, *higher* daily production. Reduction of noise is another important factor. And this completely self-contained, fully automatic, HydrOILic press occupies less space than previously used equipment. In this case, the user designed his own automatic feed device for the versatile MULTIPRESS . . . made easier by the unit's clean lines and smooth surfaces.

Built in 4, 6, and 8-ton capacities, MULTIPRESS is bringing similar production gains and efficiency to scores of production jobs. Standard accessories, such as, straightening fixtures, extension tables, bolster plates, indexing tables and others are available for these manually controlled or automatic cycling units . . . plus the amazing new Vibratory Ram Action, which provides automatically-delivered, short ram strokes at frequencies up to 500 per minute, with each of those strokes exerting closely regulative, uniform pressure on the work! Even the number of those vibratory strokes per ram cycle may be controlled automatically. Write for details!

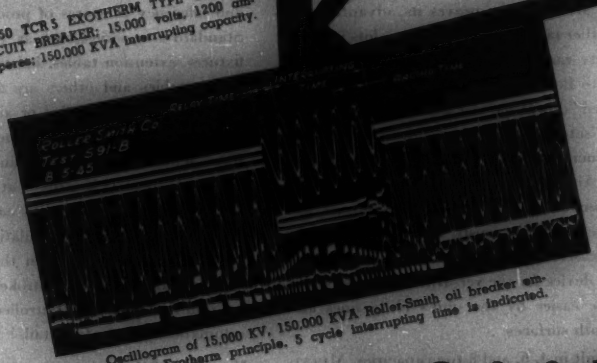
The DENISON Engineering Co.
1192 Dublin Rd., Columbus 16, Ohio

New



Curves of acceleration, velocity and arcing time derived from breaker test oscillogram.

150 TCR 5 EXOTHERM TYPE OIL CIRCUIT BREAKER: 15,000 volts, 1200 amperes; 150,000 KVA interrupting capacity.

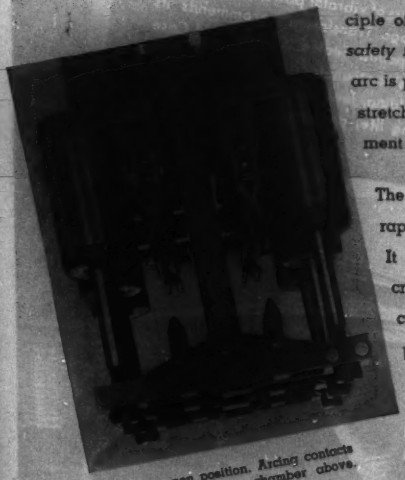


Oscillogram of 15,000 KV, 150,000 KVA Roller-Smith oil breaker employing Exotherm principle. 5 cycle interrupting time is indicated.

ROLLER

ROLLER-SMITH BREAKER

Gives 5 Cycle Opening with newly discovered EXOTHERM principle of Arc Extinction - - -



Breaker in open position. Arcing contacts shown with quenching chamber above.

THE new Roller-Smith oil circuit breakers with the Exotherm principle of arc extinction give 5 cycle opening consistently, a *38% safety factor over present accepted standards.* That's because the arc is put out by use of its gas generated energy instead of merely stretching the arc. Users are assured greater protection to equipment by this higher opening speed.

The operation of a confining chamber to quench the arc rapidly is based on the known properties of gas conductivity. It decreases with decrease in gas temperature and also decreases with an increase in pressure. In the quencher the cooling of the arc extracts its energy and reduces the temperature. At the same time the enclosure builds up the gas pressure so that it becomes less conducting and the combination puts out the arc.

The greater speed on opening cuts down contact burning and thereby reduces contact maintenance. It also gives improved protection to equipment against short circuits because of the higher speed of opening.

Confining the gas within the quenching chamber to put out the arc keeps the pressure within the tank at a safe nominal value.

For full information on the Exotherm principle applied to Roller-Smith oil circuit breakers, write to dept. EE-5

SMITH

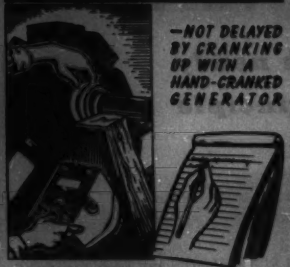
Oil Circuit Breakers

BETHLEHEM • PENNSYLVANIA

In Canada: Roller-Smith Maryland, Ltd., Kitchener, Ontario

STANDARD AND PRECISION ELECTRICAL INSTRUMENTS • AIRCRAFT INSTRUMENTS • SWITCHGEAR
AIR AND OIL CIRCUIT BREAKERS • ROTARY SWITCHES • RELAYS • PRECISION BALANCES

He's making an
ACCURATE
INSTANT READING
of INSULATION RESISTANCE



—NOT DELAYED BY CRANKING UP WITH A HAND-CRANKED GENERATOR

That means he is using a
VIBROTEST
INSULATION RESISTANCE TESTER

Model 201 Vibrotest Range O-200 Megohms at 500 volts potential O-2000 Ohms, 150-300-600 Volts AC or DC. One of 36 models.

SELF-CONTAINED

Power source produces constant potential of 500 volts.

NO CRANKING.

NO LEVELING.

ONE-HAND operation, level or at practically any angle.

EASILY READ scale shows ohms and megohms.

SEVERAL COMBINATIONS of AC and DC voltages available.

COMPACTLY CASED, easily portable. Ideal tester for quick *dependable* time-saving testing by electrical contractors, maintenance superintendents, and others responsible for protection of equipment. One of 36 Vibrotest models for every requirement.

Send for Bulletins

Associated Research also makes HYPOT, all-purpose insulation breakdown tester. VIBRO-GROUND, ground resistance tester, and many others. Full facilities for repair of electrical instruments.

Engineering Service Representatives in All Principal Cities.

ASSOCIATED RESEARCH, Inc.

221 So. Green St., Chicago 7, Ill.

Tel. STAte 6076

VIBRATOR
TRANSFORMERS
Efficiently Shielded
by
Drawn Steel Cases
Pioneers of vibrator power transformers, Chicago Transformer recommends its Compound Sealed Drawn Steel Case construction to achieve maximum shielding, long and dependable operating life, and simplicity of mounting.
C. T. also makes...
Power transformers for radio and other electronic circuits, audio and filter reactors, instrument transformers, auto and central transformers, power filters, fluorescent ballasts and ignition coils.
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DIVISION OF ESSEX WIRE CORPORATION
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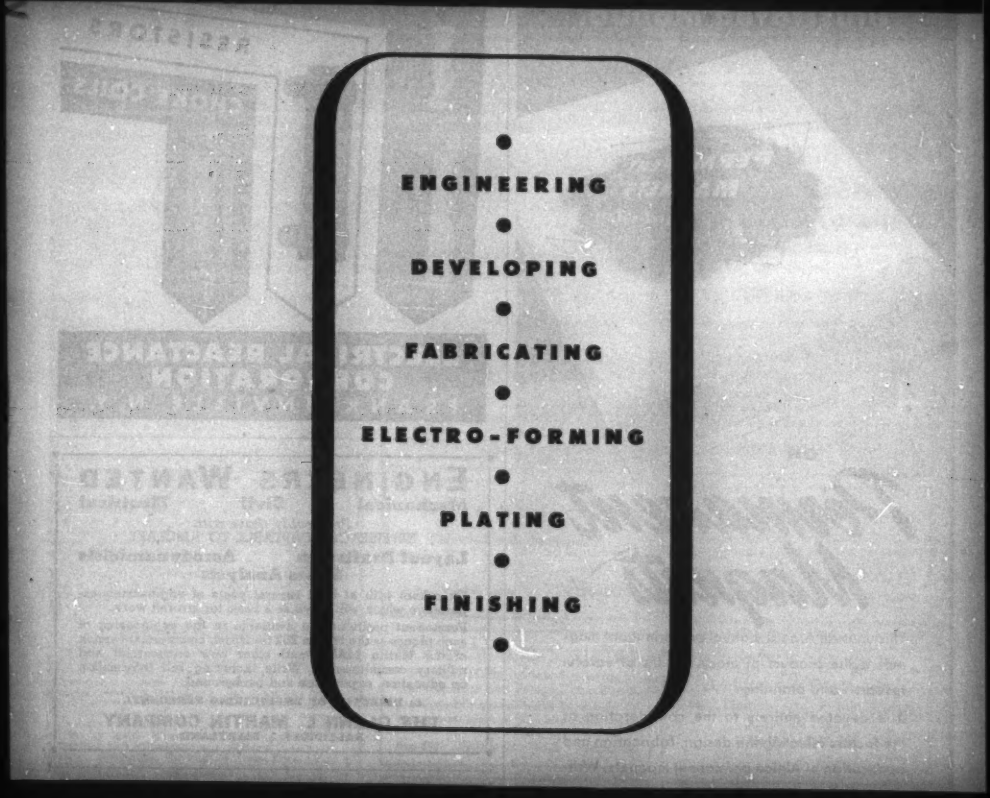
CHICAGO 18

METAL ASSEMBLIES AND COMPONENTS
FOR
ELECTRONIC AND MECHANICAL DEVICES



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MANUFACTURERS OF QUALITY METAL PRODUCTS SINCE 1867

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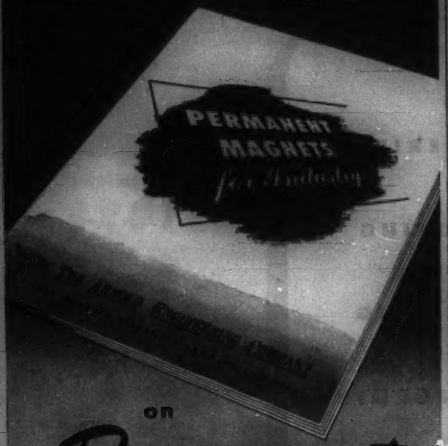
A complete 24 page Illustrated Manual



on

Permanent Magnets

This unusual Arnold manual on permanent magnets is the product of many months of careful research and planning.

It is devoted entirely to the consideration of the factors affecting the design, fabrication and application of Alnico permanent magnets. Written entirely by Arnold engineers, its purpose is to help engineers in industry to better utilize the magnetic and physical characteristics of the Alnico alloys in arriving at efficient design.

WRITE TODAY,

on your letterhead, for your free copy

THE ARNOLD ENGINEERING COMPANY

147 EAST ONTARIO STREET, CHICAGO 11, ILLINOIS

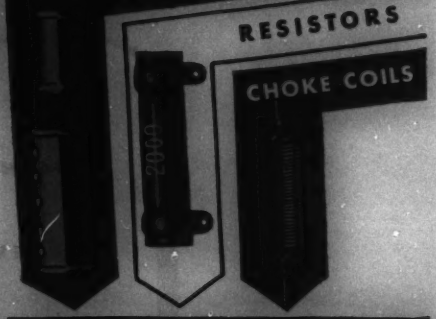
Specialists in the Manufacture of ALNICO PERMANENT MAGNETS

Hi-Q

. . . CAPACITORS

RESISTORS

CHOKE COILS



ELECTRICAL REACTANCE CORPORATION

FRANKLINVILLE, N. Y.

ENGINEERS WANTED

Mechanical Civil Electrical

Preferably those with
EXPERIENCE ADAPTABLE TO AIRCRAFT

Layout Draftsmen Aerodynamicists
Stress Analysts

Or others with at least several years of engineering experience which will serve as a basis for aircraft work.

Permanent positions are available in the engineering of such planes as the Martin 202 transport, commercial version of the Martin MARS, and other new commercial and military commitments. Write including full information on education, experience and background,

to DIRECTOR OF ENGINEERING PERSONNEL

THE GLENN L. MARTIN COMPANY
BALTIMORE 3, MARYLAND

FEDERAL ELECTRIC PRODUCTS COMPANY

50 Paris St., Newark, N. J.

offers an unusual sales and engineering opportunity in the home office, to men experienced in motor controls, safety switches and panelboards.

If not thoroughly experienced as sales manager, a qualified man will be trained; adequate salaries will be paid.

Write attention of Mrs. E. Palmer, giving complete background.

Engineering Societies Personnel Service, Inc.

New York — 8 West 40th St.
San Francisco — 57 Post St.
Chicago — 211 West Wacker Dr.
Detroit — 100 Farnsworth Ave.

In applying for positions advertised by the Service, the applicant agrees, if actually placed in a position through the Service as a result of these advertisements, to pay a placement fee in accordance with the rates as listed by the Service. These rates have been established in order to maintain an efficient, non-profit personnel service and are available upon request. This also applies to registrants whose notices are placed in these columns.

All replies should be addressed to the key numbers indicated and mailed to the New York Office.

Men Available

ELEC-MECH ENGR; graduate; 20 yrs des, constr, and opers; 17 yrs in responsible charge. Exper covers heavy machinery, diesel-generation, substations up to 110 KV, pumping systems, etc; last 3 yrs Chief E.E. for large industrial. E-104.

ELEC ENGR; E.E. and M.E.; married; 30 yrs exper des, constr, pwr plants, substations, distr systems, and indus plants; 5 yrs executive exper charge engg dept large util syndicate; 5 yrs purchase engg eqpt for foreign interest; languages, English, German, Russian, Armenian, Turkish; available immediately service design, constr, purchase. E-112.

ELEC ENGR; member AIEE, IRE, SPEE; age 31; desires pos as asst prof in western school. Four yrs teaching exper including supv of elec lab; also devpmt exper in UHF and familiarity with electronics. Available 2nd semester or next year. E-139.

ELEC ENGR; Lehigh 1939; exper in managment, devpmt and prod in communication field, traveled extensively, enjoy large acquaintanceship. Pos desired with future dependent on initative and contact. E-140.

ELEC ENGR; graduate, license; age 31; exper indus des, layout, constr, indus electronic eqpt. Last 2 yrs Chief E.E. large industry. Available immediately. Prefer N. Y. area or foreign. E-142.

FIELD ENGR, Radar; age 28; exper instruction, installation and service radar eqpt aboard combat vessels; 2 yrs supv inspection airborne radio-radar in field for U. S. Navy Dept. Desires pos future in radio, indus electronics field. Prefer factory representative. Any location. E-143.

ELEC ENGR; graduate; age 42; 3½ yrs on vital electronic war project. Supv small group engaged in special testing. Preparation of tech reports. Some electronics and UHF. Fifteen yrs large pwr co; distr engg, relay protection, diagrams, statistics, testing. Adaptable to changing conditions. Prefer greater N.Y.C. E-144.

ELEC ENGR; 21 yrs exper. Des and constr indus and central station plants, including synthetic rubber, shell loading, and uranium fission plants. Also exper in pub util rates, costs and market studies. E-145.

Positions Available

ELECTRICAL ENGINEERS. (a) Electrical Engineers to be trained for patent work in the electronics field, particularly radio. Apply by letter submitting complete details of education, experience and salary requirements. (b) Graduate Electrical Engineer having experience in the preparation and prosecution of U. S. patent applications, preferably in electrical fields, including radio. Apply by letter submitting complete details of education and experience and indicate salary expected. Locations, vicinity of New York City. W5759.

ELECTRICAL ENGINEER, young, preferably with some laboratory experience, who would be interested in carrying on research in the field of dielectrics and also help with the design of electrical circuits. Location, Maryland. W5786.

ENGINEER, electrical, to start a research laboratory for a manufacturer concerned with fabrication of phonograph records. Write stating age, education and experience. Location, Pennsylvania. W5993.

ASSISTANT PROFESSOR of electrical engineering, preferably with Ph.D. degree and research experience, to teach power and communications. Location, Pennsylvania. W6003.

ELECTRONIC AND DEVELOPMENT ENGINEER, electrical graduate preferred, for operation and maintenance of electronic vibration measuring equipment. Laboratory and field testing involved under supervision of senior engineer. Salary, $2700 a year. Location, western Pennsylvania. W6006(5).

SALES ENGINEER, young, electrical graduate, who has sold maintenance items to industrials and accessories to motor manufacturers in the East and Middlewest. W6089(c).

ELECTRICAL ENGINEER for development research in electronics for leading manufacturer of cans and containers located in Chicago. Work involves high frequency induction and dielectric heating. Salary, up to $4000 a year. R7981C.

Professional Engineering Directory

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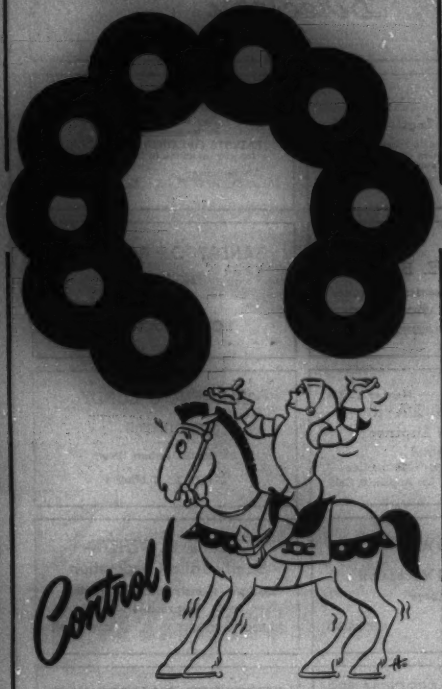

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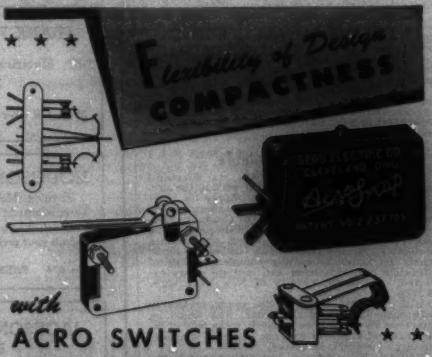

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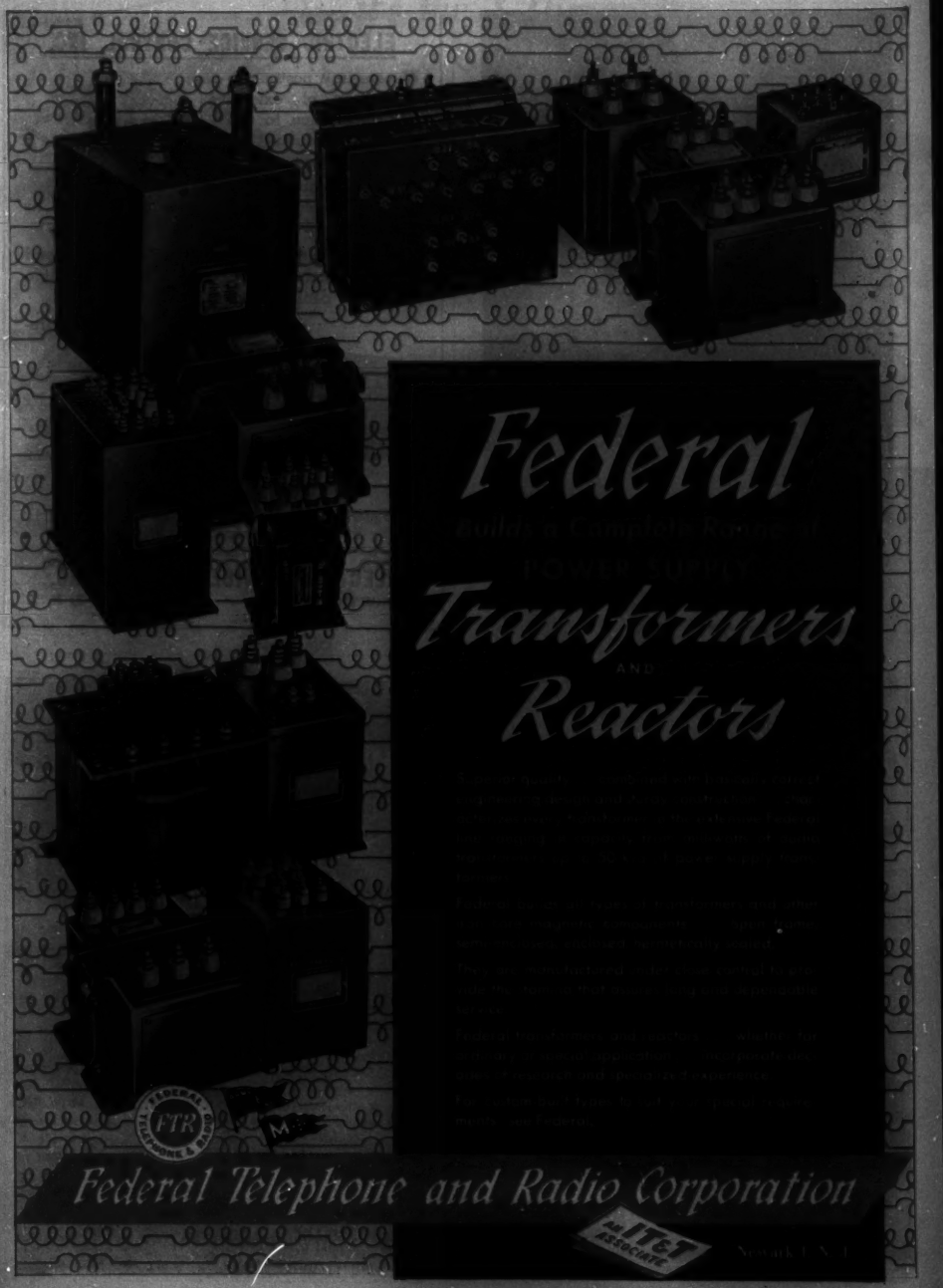
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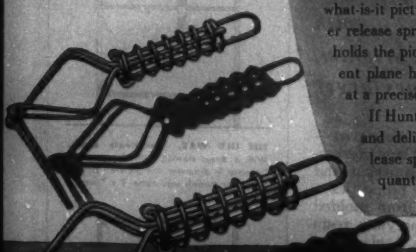
In Springs— it's the X-Dimension that gives a Glider and You a Lift

Ever hear of the X-Dimension of a Spring? Probably not. But, sure as you're born it's there, in every spring. Take, for instance, the intriguing what-is-it pictured below. It's a glider release spring, an assembly which holds the pick-up rope until the parent plane hitches on—then let's go at a precise jerk on the towline.

If Hunter had only manufactured and delivered dependable glider release springs on time and in needed quantities, its job would have been satisfactory. But Hunter invented the device for All American Aviation, Inc., and assigned the patents to them. That's the X-Dimension at work.

It's also at work in such pioneering efforts in spring manufacture as control gaging and statistical methods in quality control. It's your guarantee of good springs, your insurance against failures and customer complaints. It's *more* than you bargained for—in springs.



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Science in Springs

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MEMO TO PURCHASING MEN—

• Next time your engineers hand you a tough spring procurement job, let Hunter help you get your money's worth.

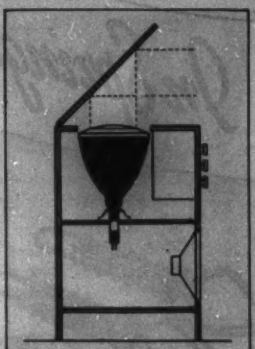
NEW TELEVISION LENS OF DU PONT "LUCITE"

Helps bring the new home receiving sets at popular prices . . . with screen images brighter, clearer . . . 5 times larger

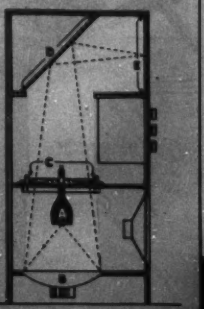
THE TELEVISION SET you will have in your home soon—it's ready now—will show on a screen a picture big enough to see . . . with ease and without distortion.

The new method "does it with mirrors" . . . adapts a well-known principle of astronomical photography. But while the astronomers need not care too much about the cost, the maker of television sets for millions of average Americans has to care—tremendously. The new method of producing television sets within a popular price range is made possible by the discovery that a basic part—an aspherical correcting lens possessing excellent light-transmission and low-scattering of light properties—can be mass produced from molded "Lucite" methyl methacrylate resin in a matter of minutes. A glass lens of equivalent quality requires days of skilled grinding and polishing.

"Lucite" has proved its worth helping to win the war. *It is now available for peacetime applications.* E. I. du Pont de Nemours & Co. (Inc.), Plastics Department, Arlington, New Jersey.



THE OLD WAY. Relatively small. With a direct-viewing cathode-ray tube, 12 inches in diameter, the picture you saw in prewar models was about 9 x 7 inches.



THE NEW WAY. Larger, clearer. By reflecting the rays from a spherical mirror (see diagram) and using a correcting lens of "Lucite," a tube only 5 inches in diameter produces an image which fills a screen 21½ x 16 inches, and with greater clarity. The reflective optical system, lens and sets developed by RCA Laboratories to be produced after the war by RCA Victor Div. of the Radio Corp. of America.

This Lens Projection System utilizes a brilliant image on the face of the cathode-ray tube (A) projected down on the spherical glass mirror (B), then reflected up through the "Lucite" correcting lens (C) on a flat mirror (D) which throws a focused image on the translucent viewing screen (E)

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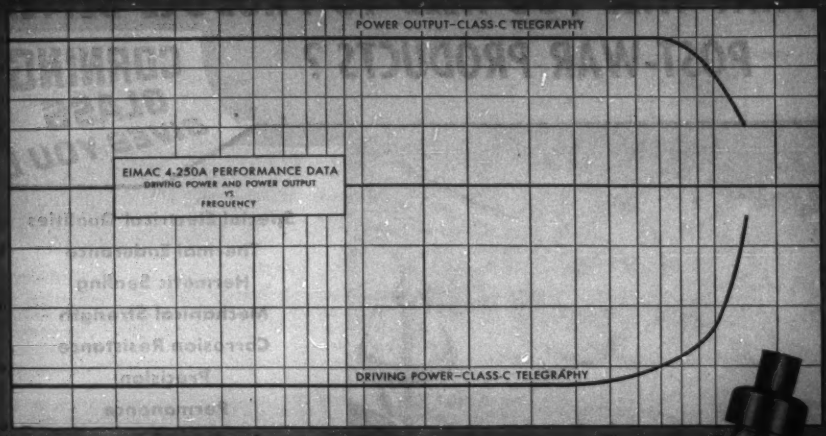

NEW EIMAC 4-250A TETRODE

Heading a parade of sensational new tubes now in production, the Eimac 4-250A Tetrode—introduced several months ago—is already in great demand. It may pay to check these performance characteristics against your own requirements.

As can be seen by the chart above, the new Eimac 4-250A Tetrode will deliver 750 watts output at frequencies up to 70 Mc. with a driving power of only 5 watts. At frequencies up to 40 Mc. an output of 750 watts may be obtained with a driving power of 3.5 watts.

The grid-plate capacitance of 0.12 *uu*fd. is extremely low, allowing operation at high frequencies without neutralization. Use of Eimac "X" process control grid reduces both primary and secondary emission which provides utmost stability.

You are invited to supplement the information given here with a technical bulletin on Eimac 4-250A Power Tetrode. It contains an elaboration of the tube's characteristics and constant current curves. Send your name and address and a copy will go to you by return mail.

The Lid's Coming Off...
Watch your favorite trade journals for announcements of other new Eimac tubes to be released this year.

CAUTION! Check serial numbers on Eimac tubes before you buy. Be sure you're getting newest types. Look for latest serial numbers.

TYPE 4-250A—POWER TETRODE
ELECTRICAL CHARACTERISTICS

Filament: Thoriated Tungsten	
Voltage	5.0 volts
Current	14.5 amperes
Plate Dissipation (Maximum)	250 watts
Direct Interelectrode Capacitances (Average)	
Grid-Plate	0.12 *uu*fd.
Input	12.7 *uu*fd.
Output	4.5 *uu*fd.
Transconductance (I_B = 80 ma., E_B = 3000 v., E_{C2} = 500 v.)	4000 *u*mhos

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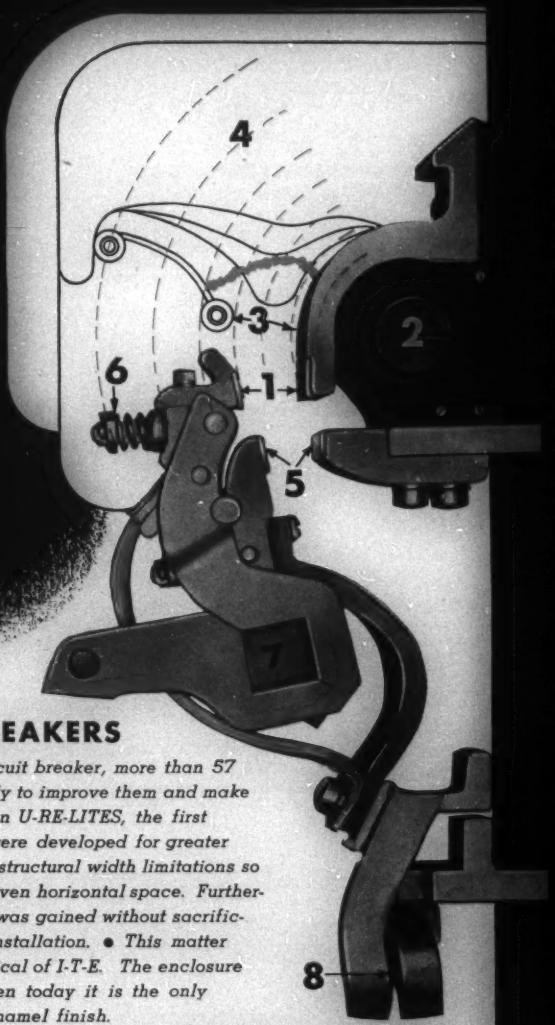

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Ever since I-T-E introduced the air circuit breaker, more than 57 years ago, we have worked continuously to improve them and make them more valuable to the user. When U-RE-LITES, the first circuit breakers enclosed in metal, were developed for greater safety and reliability, we designed to structural width limitations so that more U-RE-LITES would go in a given horizontal space. Furthermore, this advantage of narrow width was gained without sacrificing "connection room" for ease of installation. • This matter of improvements in U-RE-LITES is typical of I-T-E. The enclosure was made strong and rugged, and even today it is the only enclosure having a durable baked enamel finish.

You take no chances *when you specify I-T-E protective equipment because I-T-E specializes in the design and construction of air circuit breakers and can better supply your needs. Ask your I-T-E representative for Bulletin 1301, or write to the I-T-E Circuit Breaker Company, 19th and Hamilton Streets, Philadelphia 30, Pa.*

U-RE-LITES are fast, safe, dependable because: The wiping action of the arcing contacts (1) insures clean surfaces and minimum arc. The magnetic field of the blow out coil (2) sweeps the arc upward between arcing horns (3) which stretch the arc so that it is easily broken up by the arc chute (4). Main contacts (5) as well as sparking contacts, are made of a special silver alloy to assure long life and are readily removable without interfering with brazed or bolted circuit connections. Contact pressure springs (6) are located outside of current path. All operating arms are kept in alignment by a heavy square insulated shaft (7) and the direct-acting overcurrent trip is operated by all of the circuit current passing in the coil (8).

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FOR THE HIGHEST-GRADE LABORATORY STANDARD WORK—Type JP-4. The ratio and phase-angle errors in this transformer are negligible. It is of the wound-primary construction with taps in the primary coil for ratings of 0.25 to 60 amperes. Fuses protect the low-rated primary coils, and the secondary is provided with a Thyrite* protector.

These three types are the latest additions to our line of portable instrument transformers. The complete line includes current transformers for ratings of 0.25 to 2500 amperes, and potential transformers for 240 to 4800 volts.

For further information on portable instrument transformers to meet your field or laboratory requirements, write to the nearest G-E office or to Apparatus Dept., General Electric Company, Schenectady 5, N. Y.

*Trade-mark reg. U.S. Pat. Off.

JP-2 JP-4 JP-3

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